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# Effectiveness and cost-effectiveness evaluation of an advanced artillery weapon system

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Monterey, California. Naval Postgraduate School

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**EFFECTIVENESS AND COST-EFFECTIVENESS  
EVALUATION OF AN  
ADVANCED ARTILLERY WEAPON SYSTEM**

by

Giora Arbel

September 1992

Thesis Advisor:

D. C. Boger

Approved for public release; distribution is unlimited.

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**Effectiveness and Cost-Effectiveness Evaluation of an  
Advanced Artillery Weapons System**

by

Giora Arbel  
Chief Engineer, Israel Military Industries  
B.S.C., Technion Haifa, Israel, 1977

Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL  
September 1992

Author:

Giora Arbel

Approved by:

D. C. Boger, Thesis Advisor

S. H. Parry, Second Reader

P. Purdue, Chairman,  
Department of Operations Analysis

## **ABSTRACT**

This thesis examines the role of modern artillery as a defensive as well as offensive weapon—one which is capable of destroying targets and achieving an advantage on the battlefield rather than merely performing traditional tasks of attrition. The thesis demonstrates that the new capabilities can be attained. A new concept of artillery weapon system—the Trajectory Corrected Artillery Rocket system (TCAR)—is analyzed. Results show that this new artillery system, when it contains a cluster bomblet warhead, is very effective against infantry in an open area, with destruction levels of 50 to 90 percent, but it is not sufficiently effective against fortified and armored targets. However, when this system accommodates SFM ("smart") submunitions, it proves effective against armored vehicles, with destruction levels of up to 70 percent. Simulation programs were developed which assessed damage levels on a variety of targets. A set of these targets was chosen for which a comparison analysis was made between the TCAR and two other well-known artillery systems: 155 mm gun and a free-flight artillery rocket system. Two parameters were tested: rate of kill and marginal cost. Results demonstrate the clear advantages of using TCAR over the other systems when accompanied by a cluster warhead. Furthermore, it was found that the TCAR is the currently preferred system suitable for SFM.

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## **TABLE OF CONTENTS**

<b>I. INTRODUCTION.....</b>	<b>1</b>
A. THE ROLES AND CHARACTERISTICS OF MODERN ARTILLERY .....	1
B. TRAJECTORY CORRECTED ARTILLERY ROCKET SYSTEM .....	2
1. TCAR Operation Concept.....	2
2. More-Detailed Engineering Description Restrictions .....	3
C. GOALS OF THIS THESIS.....	4
D. METHODOLOGY.....	4
E. INPUT DATA.....	5
F. SIMILAR ANALYSIS WHICH HAS BEEN PUBLISHED.....	5
<b>II. THE MODEL AND ITS IMPLEMENTATION.....</b>	<b>6</b>
A. INTEGRATION METHOD TO ASSESS DAMAGE LEVEL OF HOMOGENEOUS TARGET .....	6
1. Damage Assessment Model of a Homogeneous Target.....	6
2. Model Application .....	11
3. Program Execution Analysis.....	12

B. SIMULATIONS OF TARGET DAMAGE ASSESSMENT FROM CLUSTER BOMBLET WARHEADS.....	12
1. Simulation Program of Small Targets When Firing Unit Size is Not Considered.....	12
2. Simulation Program of Small Targets When Firing Unit Size and Rate of Firing Are Considered .....	14
C. SIMULATION OF TARGET DAMAGE ASSESSMENT FROM SMART SUBMUNITION WARHEADS.....	17
D. OTHER PROGRAMS .....	18
1. Dealing With Large Targets.....	18
2. Consecutive Statistical Calculations.....	20
E. RUNNING THE PROGRAM.....	20
1. Systems Data.....	20
2. Simulation Output .....	26
 III. TARGET DAMAGE ASSESSMENT.....	27
A. TARGET DESCRIPTIONS AND RESULTS .....	27
1. Target Number 1: Uniform And Homogeneous Density— Troops.....	27
2. Target Number 2: Troops in an Open Area, Nonsymmetrical Homogeneous Target.....	35
3. Target Number 3: Troops in a Company at a Defense Site.....	39
4. Target Number 4: Self-Propelled Armored Howitzer Gun Battery in Firing Deployment .....	41
5. Target Number 5: Soft Vehicles, Logistic Convoy .....	47

6. Target Number 6: Mixed-Type Target In Defense Position.....	51
7. Target Number 7: Armor in an Offensive Site.....	56
8. Target Number 8: Artillery Weapon with SFM Submunition as an Anti-Tank Weapon .....	57
<b>IV. CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>62</b>
A. EFFECTIVENESS AND MARGINAL COST.....	62
B. ACCURACY.....	62
C. RECOMMENDATIONS.....	63
APPENDIX A     NUMERICAL INTEGRATION OF THE PROBABILITY DENSITY FUNCTION OVER AN HOMOGENEOUS TARGET AREA— PROGRAM CODE.....	64
APPENDIX B     TARGET DAMAGE ASSESSMENT, SIMULATION PROGRAMS CODE.....	67
LIST OF REFERENCES .....	90
INITIAL DISTRIBUTION LIST.....	91

## I. INTRODUCTION

### A. THE ROLES AND CHARACTERISTICS OF MODERN ARTILLERY

Artillery weapons were never considered main actors on the battlefield or a destructive force with a unique mission. The conventional theory of the role that artillery plays on the battlefield is that it is a weapon which supports assault and defense forces—it acts as an attrition and suppression weapon assisting main forces. Another important facet of the nature of artillery weapons, according to this convention, is that they cover area targets (as opposed to pinpoint-accurate antitank weapons).

However, a modern view is that artillery weapons, in addition to their conventional tasks, also act as main forces with unique missions. In addition, they have accurate singular destructive capabilities. This new concept permits the use of artillery for the following missions:

- Breaking massive assault forces of superior numbers, and
- Attacking high-priority long-range targets.

Modern artillery is characterized as:

- Capable of massive fire power operating in small units
- Long-range (more than 30 km)
- Destructive capability for a variety of targets (including "hard" targets)
- High survivability of launching units on the battlefield

Newly developed artillery rocket systems were expected to achieve all the above requirements, and they are indeed effective. Due to their low accuracy, however, they were found not to be cost-effective weapons.

Newly developed artillery rocket systems were expected to achieve all the above requirements, and they are indeed effective. Due to their low accuracy, however, they were found not to be cost-effective weapons.

## **B. TRAJECTORY CORRECTED ARTILLERY ROCKET SYSTEM**

The Trajectory Corrected Artillery Rocket system (TCAR) is a new concept of an artillery weapon which is in a feasibility study stage at the Israel Military Industries (IMI) Ltd. TCAR could be defined as a semi-guided missile, but we have chosen not to call it such because this family of weapons system has an entirely different structure and purpose. The system has all the advantages of the modern artillery rocket systems, as mentioned above. By controlling the rocket trajectory, accuracy is substantially enhanced. As a result, force effectiveness and system cost-effectiveness may be significantly improved.

### **1. TCAR Operation Concept**

A rocket equipped with only a simple steering mechanism is fired from a launcher. A ground station, located near the launcher, tracks the rocket trajectory. At a certain point along the trajectory, the ground station computer simulates the expected hit points based on the data gathered from this tracking and compares them to the target location. A correction command is sent to the rocket, which then performs the correction. The tracking system process continues in a closed loop until the rocket disappears from line of sight.

The TCAR is neither a pinpoint-accurate missile nor an inexpensive free-flight ballistic weapon—it stands between those two categories. The addition of an inexpensive (but not perfectly accurate)

guidance facility to the free-flight rocket increases the unit cost, but the cost is still significantly less than that of a missile. Therefore, the TCAR is capable of being employed extensively as an artillery weapon.

This thesis evaluates the Trajectory Corrected Artillery Rocket system's effectiveness and cost-effectiveness as compared to two other artillery systems:

- Extended range howitzer guns
- Modern free-flight rocket systems.

An extended-range howitzer gun is called a Rocket Assisted Projectile (RAP) or Base Bleed (BB). Modern free-flight rocket systems are currently being used in the US as MLRS and in Israel as LAR160.

Two types of warheads will be discussed:

- Cluster warhead with antipersonnel/antiarmor (ap/am) scatterable bomblets
- "Smart" warheads which contain scatterable "sense and destroy" antiarmor/antitank submunitions (This thesis text uses the alternative name, Sensor Fuzed Munitions [SFM].)

Models of some typical terrain targets were chosen on which troops, artillery, armored personnel carriers and tanks were located.

## **2. More-Detailed Engineering Description Restrictions**

The TCAR concept already exists in the form of an Israeli classified system, so a complete description of that system is not possible here and the engineering details cannot be discussed. However, performance data relevant to a generic TCAR system will be used in the models of this thesis.

### **C. GOALS OF THIS THESIS**

The goal of this thesis is to generate quantitative data that will be used by the system's developer to assess cost-effectiveness in the acquisition of the new system by potential customers (armies). Main points to be included are:

1. The effectiveness which is achieved when artillery rocket system accuracy is enhanced, and
2. A comparison of the cost-effectiveness of competitive artillery weapons in order to test the feasibility of this new concept.

It is not within the scope of this thesis to carry out a full combat deployment analysis of each weapon system.

### **D. METHODOLOGY**

The work includes building simulation programs that will accept, as input, all the parameters of those random factors affecting the performance of each system. This will result in an evaluation of the effectiveness of each system on the specific target models.

The simulation results will determine the number of rounds for each system that must be fired in order to achieve various target damage criteria. Cost-effectiveness (i.e., cost per target destruction level) is calculated accordingly.

The following additional factors will be considered:

- Rate of fire
- Size of the firing units
- Survivability of the firing units

## **E. INPUT DATA**

The particular systems on which the simulation will be performed for comparison with the TCAR are:

- G155— 155 mm howitzer gun, using as ammunition the RAP (Rocket Assisted Projectile)
- MARS (Multipurpose Artillery Rocket System)— based on the rocket system LAR160 (or its derivatives) that was developed and is currently produced by the IMI, Ltd.

All the data necessary for the simulation was provided by IMI as real data. However, because the TCAR is under development, analyses must be based on continually updated data for the system as it becomes available.

## **F. SIMILAR ANALYSIS WHICH HAS BEEN PUBLISHED**

Due to the new military applications of the systems and warheads which were analyzed, no comparable studies could be found in the open literature. IMI's Operational Analysis Department and some of the Israel Defense Forces operational research branches have done damage analysis for weapon systems that carry cluster bomblet warheads. All those analysis results were printed in Hebrew, while some of them, by nature, are classified and therefore are unavailable for this thesis. Similar military US material (even unclassified) was inaccessible because of the author's status as a foreign student in the US.

The TCAR as a weapon system is a new concept, so no published analysis could be found in the unclassified literature.

General methods of target damage assessment are described in the References 1 through 4. A description of the SADARM (Sense and Destroy Submunition) is given in Reference 5. The SFM, which is described elsewhere in this thesis, is similar.

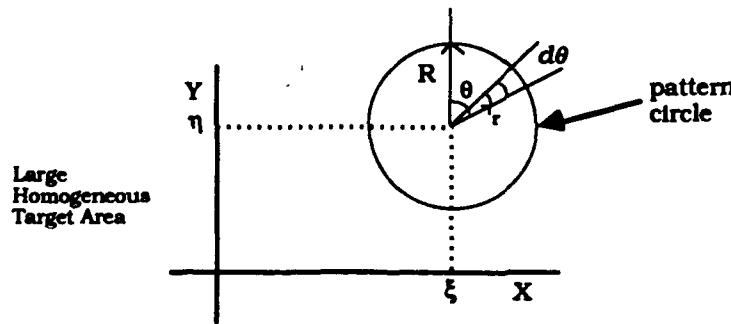
## II. THE MODEL AND ITS IMPLEMENTATION

It was essential to this thesis to write a Monte Carlo simulation model in order to evaluate target damage levels for various target types using the three alternative systems. Since an area target is the simplest type to be evaluated, the results from the simulation model were checked against an exact formulation (using numerical integration) of the area target to determine the accuracy of the simulation model. Once the simulation model generated results comparable to the exact model for the area target, the simulation model was modified with several other target types and munitions types. Missions on which salvo time duration is considered a deficiency factor and targets that contained scattered armored vehicles were also included.

### A. INTEGRATION METHOD TO ASSESS DAMAGE LEVEL OF HOMOGENEOUS TARGET

#### 1. Damage Assessment Model of a Homogeneous Target

##### a. Lethal Area of a Single Warhead



Assume that the target area is homogeneous and infinitely large and that a single warhead bursts above target area at location  $(\xi, \eta)$ . The

location of a target element inside the pattern circle of radius  $R$  is described in polar coordinates by  $(r, \theta)$  centered on  $(\xi, \eta)$ . Define  $P_{K/T}[(r, \theta)/(\xi, \eta)]$  to be the probability of kill of the target element, conditioned on the target element's location as described above. Next, define  $f_H$  to be the pdf of the rocket ballistic dispersion, and therefore  $f_H(\xi, \eta)$  is the probability that the warhead bursts at location  $(\xi, \eta)$ . Now define  $P_K[(r, \theta)(\xi, \eta)]$  to be the unconditional probability of kill of a target element whose location is given by  $(r, \theta)$  as follows:

$$P_K[(r, \theta), (\xi, \eta)] = P_{K/T}[(r, \theta)/(\xi, \eta)]f_H(\xi, \eta) \quad (1)$$

Next, define  $P_{KT}(\xi, \eta)$  to be the unconditional probability of kill by a single warhead which bursts at location  $(\xi, \eta)$  and is given by:

$$P_{KT}(\xi, \eta) = \int_0^{2\pi} \int_0^R P_{K/T}[(r, \theta)/(\xi, \eta)]f_H(\xi, \eta)rdrd\theta \quad (2)$$

$$P_{KT}(\xi, \eta) = f_H(\xi, \eta) \int_0^{2\pi} \int_0^R P_{K/T}[(r, \theta)/(\xi, \eta)]rdrd\theta \quad (3)$$

Finally, define the Mean Area of Effectiveness (MAE) as:

$$MAE = \int_0^{2\pi} \int_0^R P_{K/T}[(r, \theta)/(\xi, \eta)]rdrd\theta \quad (4)$$

The Mean Area of Effectiveness is commonly used to compare effectiveness of an artillery warhead. Using the MAE, we have:

$$P_{KT}(\xi, \eta) = MAE \cdot f_H(\xi, \eta) \quad (5)$$

### **b. Cluster Bomblet Warhead—Lethal Area**

Consider the special case where the target elements are uniformly distributed in a circle of radius  $R$ , and a cluster of  $m$  bomblets

(an equivalent area element that is killed by one bomblet). Then  $P_{kw}^m$  is the probability that a target element will be killed by at least one bomblet in the warhead and is given by:

$$P_{kw}^m = 1 - \left(1 - \frac{A_t}{\pi R^2}\right)^m \quad (6)$$

**c. Evaluation of the Proportion of Target Area That is Destroyed by a Salvo of  $n$  Rockets**

All the dispersion factors can be divided into two categories:

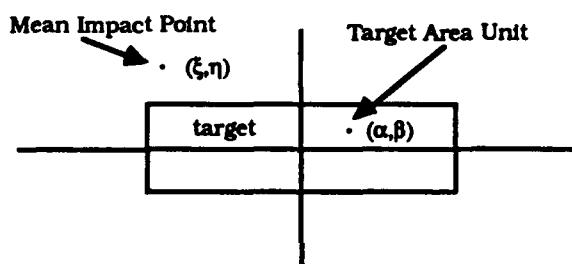
- Precision factors that create a dispersion of the salvo around the Mean Point of Impact (MPI)
- Accuracy factors that create a bias miss distance error of the whole salvo from the target center

The bias and precision factors are independent and randomly distributed according to the following:

Precision:  $f_p(X, Y) \sim \text{BIVARIATE NORMAL}(0, 0, \sigma_x, \sigma_y)$

Bias:  $f_b(\xi, \eta) \sim \text{BIVARIATE NORMAL}(0, 0, \sigma_\xi, \sigma_\eta)$

Using the following diagram.



we can define the following probabilities:

$P_t^1$  = Probability of killing a target area element at  $(\alpha, \beta)$  with one warhead,

$$P_k^1(\alpha, \beta / \xi, \eta) = \frac{MAE}{2\pi\sigma_x \sigma_y} e^{-\frac{1}{2}\left[\left(\frac{\alpha-\xi}{\sigma_x}\right)^2 + \left(\frac{\beta-\eta}{\sigma_y}\right)^2\right]} \quad (7)$$

and

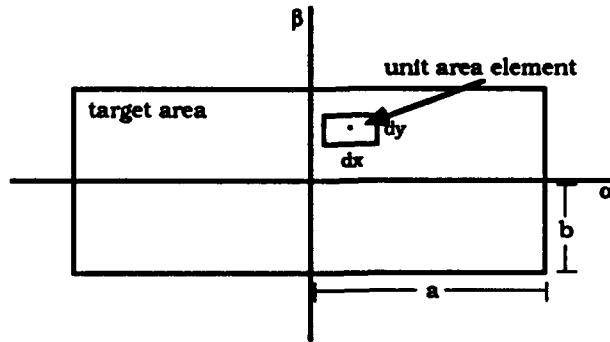
$P_k^n$  = Probability of killing a target area element at  $(\alpha, \beta)$  with a salvo of  $n$  warheads.

$$P_k^n(\alpha, \beta / \xi, \eta) = 1 - (1 - P_k^1)^n \quad (8)$$

Recall from equation 6 that  $P_{kw}^m$  is the probability that at least one bomblet from a warhead of  $m$  bomblets will kill the target. The term  $P_k^1$  in equation 8 will use  $P_{kw}^m$  in the Target Damage Assessment Program given in Appendix B. Additionally, we define  $G(\xi, \eta)$  as the expected beaten area of the target covered after a whole salvo:

$$E[A_T / \xi, \eta] = G(\xi, \eta) = \int_{-a}^a \int_{-b}^b P_k^n(\alpha, \beta / \xi, \eta) dx dy \quad (9)$$

This is illustrated in the following diagram:



Generalizing, we have:

$$E[A_T] = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{G(\xi, \eta)}{2\pi\sigma_\xi \sigma_\eta} e^{-\frac{1}{2}\left[\left(\frac{\xi-x_0}{\sigma_\xi}\right)^2 + \left(\frac{\eta-y_0}{\sigma_\eta}\right)^2\right]} d\xi d\eta \quad (10)$$

where:

$E[A_T]$  The expected kill area from all possible salvos with all possible  $(\xi, \eta)$ .

$X_0, Y_0$  The center of all possible salvos that can be taken as the center of the target (approximately, because sometimes a small fixed bias exists).

For a salvo of  $n$  rounds, we have:

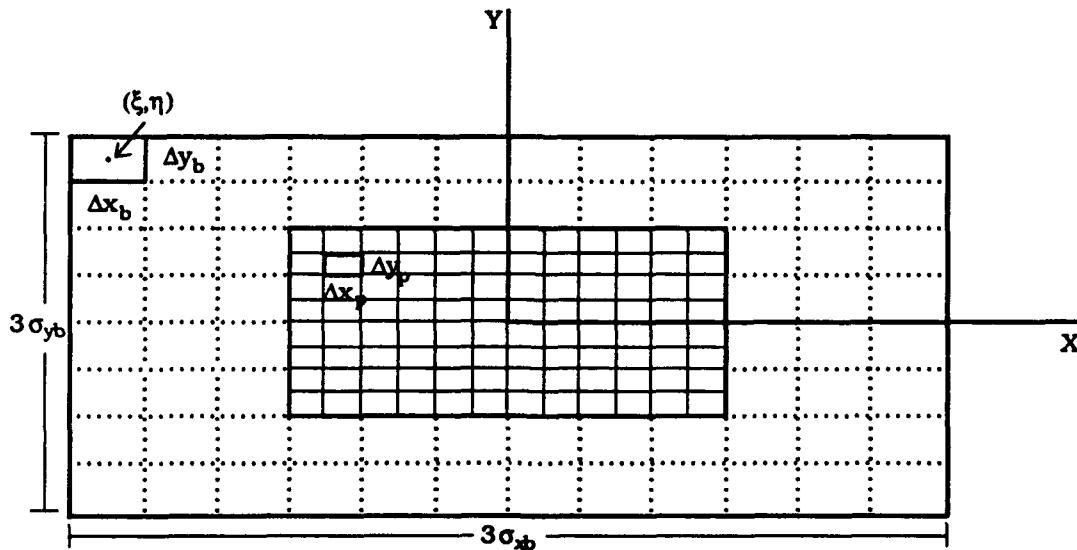
$$P_{sk}^n = \frac{E[A_T]}{4 \cdot a \cdot b} \quad (11)$$

where

$P_{sk}^n$  The proportion of target that is killed by a salvo of  $n$  rounds.

#### d. Numerical Solution Method

The above relationships can be evaluated in the following manner:



A large space around the target, of size  $3\sigma_{xb} \times 3\sigma_{yb}$ , is divided into small cells. The center of each cell will be denoted as the

argument  $(\xi, \eta)$  and the corresponding  $G(\xi, \eta)$  will be calculated for each cell. Then,

$$E[A_T] = \sum_{\xi \in T} \sum_{\eta \in T} G(\xi, \eta) \cdot f_b(\xi, \eta) \Delta X_b \Delta Y_b \quad (12)$$

where

$$f_b(\xi, \eta) = \frac{1}{2\pi\sigma_{X_b}\sigma_{Y_b}} e^{-\frac{1}{2}\left[\left(\frac{\xi}{\sigma_{X_b}}\right)^2 + \left(\frac{\eta}{\sigma_{Y_b}}\right)^2\right]} \quad (13)$$

and the proportion of the destroyed target or the probability that one element target is destroyed by a salvo of  $n$  rounds is:

$$P_k^n = \frac{E[A_T]}{4ab} \quad (14)$$

## 2. Model Application

A FORTRAN program was written incorporating the above model. The FORTRAN program code is given in Appendix A. The following results are from one set of system data made up for this program.

Results:

DESTRUCTION PROBABILITY = .4036

DESTROYED AREA (SQM) = 2018.

PDF INTEGRAL = .9946

Data:

NO. OF ROUNDS = 10

MEAN AREA OF EFFECTIVENESS (SQM) = 7877.5

TARGET HALF WIDTH (M) = 100.00

TARGET HALF LENGTH (M) = 50.00

PRECISION CROSS-RANGE STANDARD DEVIATION (M) = 100.0

PRECISION RANGE STANDARD DEVIATION (M) = 100.0

BIAS RANGE STANDARD DEVIATION (M) = 100.0

BIAS CROSS RANGE STANDARD DEVIATION (M) = 100.0

NO. OF SEGMENTS ON TARGET 10. X 10.

NO. OF SEGMENTS ON THE OPEN AREA 25.X 25.

The target pattern that is used for this program is a quarter of a rectangle. Since the target is homogeneous, the killing probability of each area element in one quarter is identical to a corresponding element in the other three. Therefore, it is sufficient to integrate over one-quarter of a target rather than the entire rectangle.

### **3. Program Execution Analysis**

1. The number of segments in the open area (last line) were found to be insensitive—any values greater than 10 gave very similar results.
2. PDF integral (line 3) is an integration of equation 13 over the whole space. It is given as an indication of the accuracy of this numerical integration. The value accepted is sufficiently close to 1.
3. The above results will be used in comparison with the Monte Carlo simulation that will be described later.

## **B. SIMULATIONS OF TARGET DAMAGE ASSESSMENT FROM CLUSTER BOMBLET WARHEADS**

### **1. Simulation Program of Small Targets When Firing Unit Size is Not Considered**

The program reads system and target data. It calls for the Salvo-round subroutine to simulate the damage level caused by firing variable rounds in a salvo.

While receiving each one of the salvo results, the program calls for the *Statistics* subroutine that calculates averages, standard deviations, and confidence intervals consecutively.

The program stops when the confidence interval for 95 percent confidence level is reduced to predetermined fixed values ("resolution"). Simulation of five target types that are deployed on the same area can be handled simultaneously.

Typically, any combination of five target types can be chosen from the following: tank, APC, artillery gun, soft vehicle, standing troops, prone troops, and troops in excavations.

**a. Subroutine Salvoround**

The subroutine accepts the target elements linked by a linked list matrix, generates bias error, generates precision error, searches for target elements inside the pattern ellipse—if found, they are eliminated from the list—and counts the number of eliminations. When the number of predetermined rounds in the salvo are completed, the subroutine returns the number of destroyed target elements to the main program.

The program uses subroutine *Rannum*, which is a random number generator. (Professor M. Bailey of the Naval Postgraduate School distributed this program to students of his Simulation class; the FORTRAN code list is given in Appendix B.)

**b. Assumptions**

1. The bomblet pattern on the ground is an ellipse in which the bomblets are dispersed evenly.
2. Bias distribution and precision distribution are both independent bivariate normal with all means equal to 0.

### **c. Testing the Program**

Running the program using the made-up data shown in subsection A.2 of this chapter with the same target yielded the following result: "damage level" (called "destruction probability" or "destroyed area proportion") = 0.397. Comparing it to 0.4036, which is obtained by the integration program, there is a difference of 1.6 percent. That difference can be explained by the termination of the simulation program when the half 95 percent confidence interval reaches a predetermined value, which had been previously fixed at 1.6 percent. Therefore, the results of the two programs agree (with a 95 percent confidence level).

Figures 1 through 3 describe the procedure.

The FORTRAN program code is given in Appendix B.

### **2. Simulation Program for Small Targets When Firing Unit Size and Rate of Firing Are Considered**

This program is similar to the previous one. The difference is that the bomblet lethal area, when firing on troop target elements, is decreased during the elapsed salvo time.

It is conceivable that standing troops, while exposed to fire, will try to find shelter. At first, they go to a prone position, and then they crawl to a shelter, which is assumed to be an excavation. For the purpose of the simulation, it is assumed that all troops are standing at time zero (i.e., the lethal area values are those of standing troops) and the lethal area is decreased exponentially with elapsed salvo time.

The lethal area at time t is given by:

$$ALT = ALX + (ALST - ALX) * EXP (- GAMMA * TIME)$$

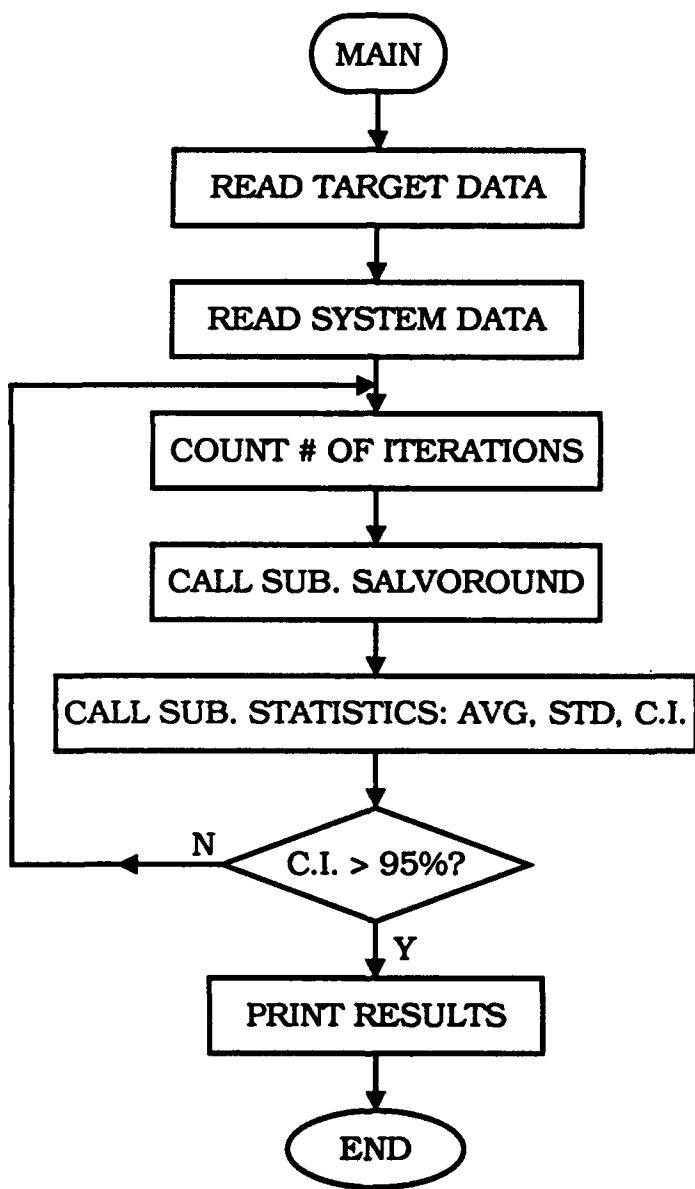
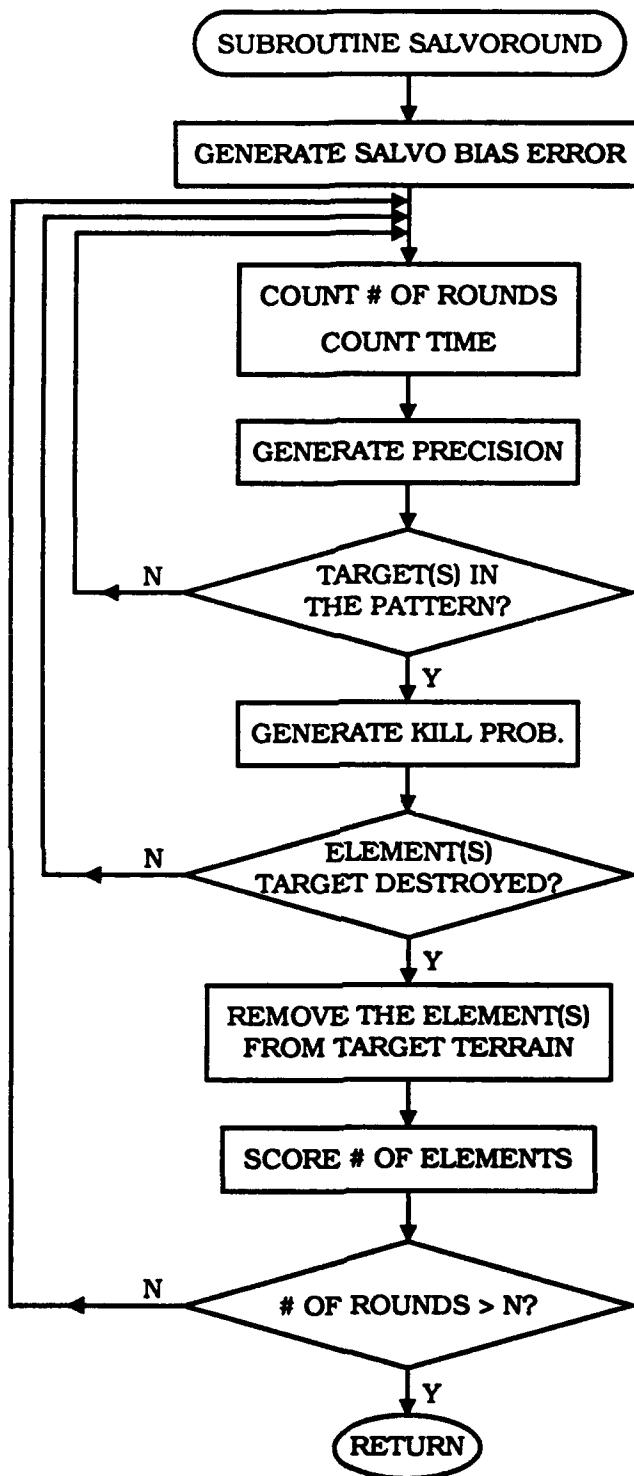
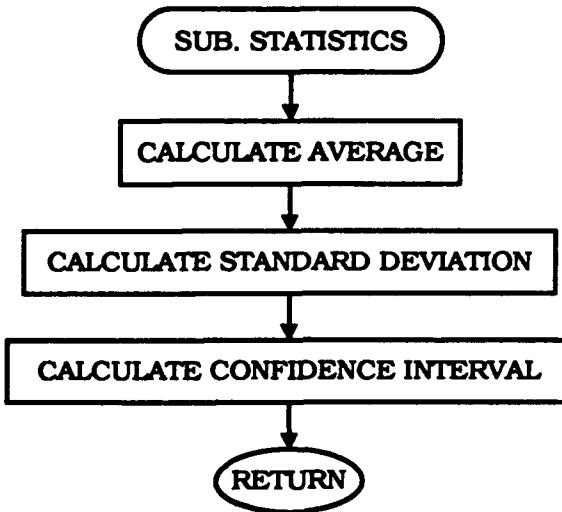


Figure 1. Simulation Main Program Flow Chart



**Figure 2. Subroutine Salvoround Flow Chart**



**Figure 3. Subroutine Statistics Flow Chart**

where GAMMA is the individual-finding-shelter rate and ALST and ALX are lethal areas of troops when standing and when in excavations, respectively.

#### **C. SIMULATION OF TARGET DAMAGE ASSESSMENT FROM SMART SUBMUNITION WARHEADS**

This simulation assessed damage to targets consisting of hard elements (armor vehicles, tanks) when hit by Sensor Fuzed Munitions (SFM).

The main program is similar to the main program for cluster munitions (B1); it calls for subroutine *Smartsalvo*. This subroutine accepts the target elements (listed in *x, y* location arrays), generates a bias error, generates precision error, generates submunition dispersion, and then searches for target elements inside the submunition searching circle. If targets are found, they are recorded in a stack for detected elements. Among the potentially detected targets, one killed target per one

submunition is chosen, in order of the farthest from the searching center first. Finally, the subroutine counts the number of killed targets. When the predetermined number of salvo rounds is completed, the subroutine returns the number of destroyed units to the main program. A flow chart of the subroutine is given in Figure 4.

The following two additional computations are required:

**1. Function PH1:**

This function determines the hit probability, given the existence of a target inside the submunition searching circle.

**2. Function PK1:**

This function determines the kill probability, given the existence of a target inside the submunition searching circle.

The FORTRAN program codes are listed in Appendix B.

#### **D. OTHER PROGRAMS**

**1. Dealing With Large Targets**

When the target is large, it is necessary to shift the aiming point in order to cover the entire target area.

The multi-aiming point procedure is essential, particularly with a more accurate weapon. A more accurate weapon hits the target at the center and the margins remain uncovered. If the weapon ballistic dispersion is high, this procedure is less important because the dispersion creates target coverage.

Functions Splitx and Splity deviate the aiming point for large targets from the center to the outer portions of the target. These functions evenly allocate the salvo rounds among the subtargets. Residuals are directed to central portions.

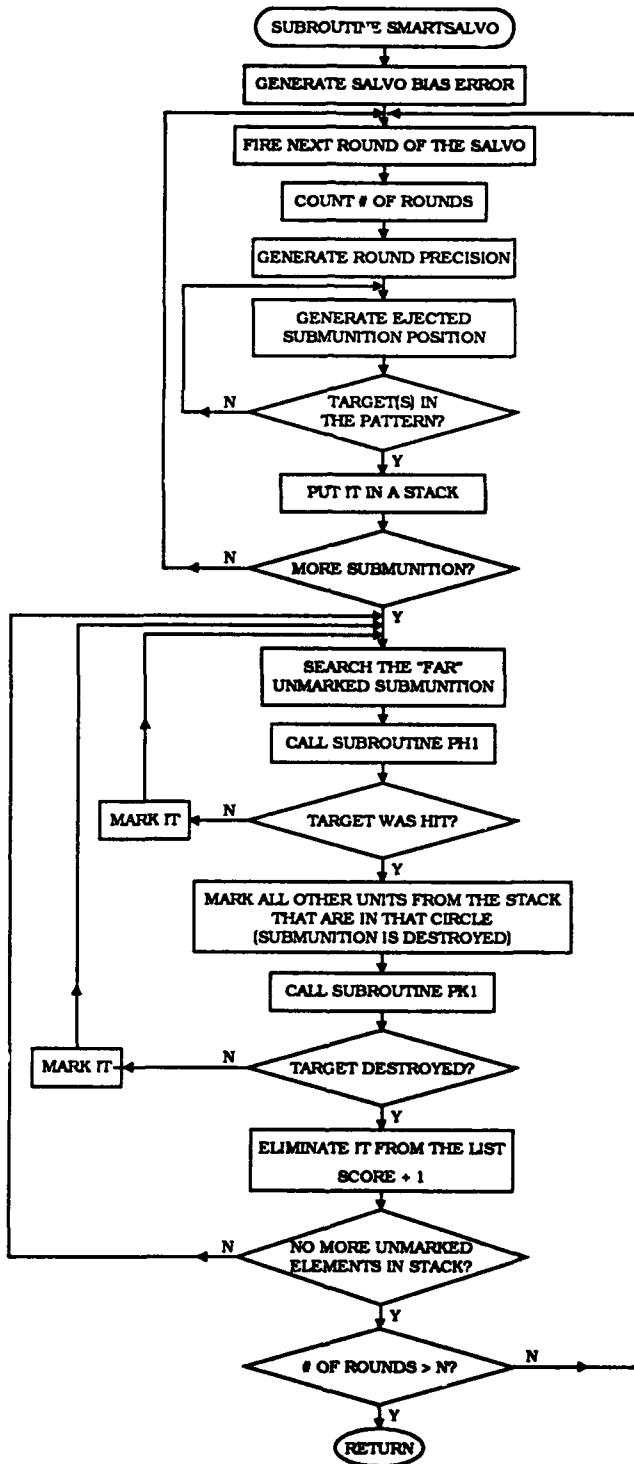


Figure 4. Subroutine Smartsalvo Flow Chart

FORTRAN function codes are listed in Appendix B.

## 2. Consecutive Statistical Calculations

The following function and subroutines were also used:

- **Subroutine Statistics** calculates the average of a current incremented sample and calls for subroutine Stdev to calculate the standard deviations.
- **Subroutine Stdev** calculates the standard deviations.
- **Function Confint** calculates the confidence intervals.
- **Subroutine Rannum**: A random number generator that provides all basic distributed random numbers.

FORTRAN codes are listed in Appendix B.

## E. RUNNING THE PROGRAM

### 1. Systems Data

#### a. Range

The analysis was done with a range of 27 km, which was chosen in order to include the 155 mm extended-range howitzer gun projectile (whose maximum range is 27 km) in the comparison analysis. Despite the general opinion of "experts" that modern guns can reach ranges longer than 27 km, the author's opinion is that this range is the practical limit of standard artillery. Tube artillery will remain at this range because any optional extension of range will be accompanied by degradation of accuracy as well as rate of fire. Hence, free-flight artillery rocket systems will do the job more effectively.

The maximum range of the MARS is 33 km. The range could actually be longer, but it was limited to 33 km due to the high dispersion of the rockets.

The TCAR range is 45 km. The range can be extended by using larger caliber rockets. The accuracy of the TCAR is not dependent on the range.

The main reasons this thesis used a 27 km range are: (1) this range is common to the above three systems; (2) by convention, 27 km is regarded as the typical artillery range for analysis purposes; and (3) the range is coincident with the limit of battlefield real-time intelligence (that limit may be extended in the near future, when the use of drones (RPVs) will be more extensive).

The following data are related to the 27 km range.

**b. Accuracy**

Bias (sometimes called "ballistic") distribution (i.e., shift of the whole salvo from the center of target) and precision distribution (i.e., dispersion of the salvo around the center of impact) are bivariate normal with means 0 and standard deviations  $\sigma_{BX}$ ,  $\sigma_{BY}$  for bias and  $\sigma_{PX}$ ,  $\sigma_{PY}$  for precision.

The standard deviations were calculated while taking into account all dispersion factors. The ballistic behavior of a free-flight object (a projectile as well as a rocket) creates independently distributed bias and precision deflections in the X and Y directions. These are shown in Table 1.

The analysis was done by running the simulation program for cluster warheads on the targets to be described.

**TABLE 1**  
**DISPERSION STANDARD DEVIATIONS**

System/Dispers.	$\sigma_{px}$ m	$\sigma_{py}$ m	$\sigma_{bx}$ m	$\sigma_{by}$ m
G155	170	36	108	34
MARS	214	187	127	107
TCAR	60	60	5	5

The target location errors are assumed to have a bivariate normal distribution with mean 0 and standard deviations  $\sigma_x$  and  $\sigma_y$ , chosen to be: 0, 25, 50 and 100 m. The Target Location Error (TLE) was pooled with the bias deviation as follows:

$$\sigma_{BXTOT} = \sqrt{\sigma_{BX}^2 + \sigma_{TLEX}^2}; \sigma_{BYTOT} = \sqrt{\sigma_{BY}^2 + \sigma_{TLEY}^2}$$

Note: The variances involved are from independent random variables.

*c. Rate of Fire*

- One gun—G155 can fire at the rate of three rounds per minute. Maximum rate of a battery of six—18 rounds per minute.
- MARS— one target is engaged by no more than one launcher at a time, with rate of 36 rounds per minute.
- TCAR— 36 rockets are available on a launcher, but the ground control system is capable of controlling 20 rockets in flight simultaneously (no matter from where they were fired). Since the flight trajectory time is approximately one minute, the rate of fire is 20 rounds per minute.

*d. Marginal Price*

Cost analysis comparisons of target damage levels between the three systems were carried out. This was done by taking into consideration the marginal cost—the cost of the rounds that were allocated to

the particular target (because they directly cause the damage to the target).

Another aspect of this topic is that the costs of Self-Propelled Guns (SPGs) and Multiple-Rocket Launchers (MRLs) are almost the same. Ground support equipment and logistics are also identical.

The exact costs of all system parts were not available. In addition, costs of weapon systems are subject to changes according to various contract factors. Therefore, reasonable costs were estimated based on the author's experience. Table 2 shows cost estimates for one round of each system.

TABLE 2  
ROUND COSTS IN DOLLARS

System/Cost	Cluster Bomblet Wh.	SFM Wh.*
G155	\$2,000	\$37,000
MARS	\$7,000	\$112,000
TCAR	\$11,000	\$116,000

\*It is assumed that SFM target production cost is \$35,000 and the canisters that contain it cost the same as the bomblets in the cluster version.

e. **Cluster Warhead Data**

The three systems with cluster warheads accommodated with CL2130 at/am bomblets are IMI Ltd. products. The bomblet is equipped with a time-operated self-destruction mechanism that eliminates the problem of duds.

Diameter: 42 mm

Length: 55 mm

Weight: 300 grams

Maximum hard steel penetration depth: 110 mm

Remark: This bomblet is not the M42-M77 commonly used by the US and NATO.

TABLE 3  
SYSTEMS CLUSTER WARHEAD DATA

System	Diameter (mm)	# of Bomblets	Radius of Pattern (m)
G155	155	49	75
MARS	160	104	100
TCAR	160	104	100

Bomblet lethal area:

Standing troops: 197 sqm

Prone troops: 83 sqm

Troops in an open excavation: 1 sqm

(It is assumed that only a direct hit into the excavation is effective.)

Tank (T62): 3.5 sqm

APC (BTR50): 5.0 sqm

SPG: 7.0 sqm (in this case, neutralization is considered rather than destruction)

Trucks: 20 sqm

*f. SFM Submunition Warhead*

Warheads are accommodated with 155 mm SFM, and each is carried inside a canister. Data for SFM submunitions are classified, so this thesis will not specifically identify the submunitions. Performances that are listed are the best guess of the author.

**TABLE 4**  
**SYSTEMS SFM WARHEAD DATA**

<b>System</b>	<b>Diameter (mm)</b>	<b># of Canisters</b>	<b>Ejection Distance (m)</b>		
G155	155	1	mean	0	sd. 5
MARS	160	3	mean	40	sd. 10
TCAR	160	3	mean	40	sd. 10

There are three stages to the operation, with three different probabilities. Given a target inside the searching circle:

- **Detection probability** is expected to be high, therefore considered to be 1.
- **Hit probability (PH)**— Given the target is detected, the probability that the forged accelerated penetrator hits the target in a vulnerable location.
- **Kill probability (PK)**— Given a target is hit, the probability of penetration and destruction.

PH and PK are functions of the distance of the target from the center of the searching circle (see Table 5):

**TABLE 5**  
**SFM SUBMUNITION DATA**

<b>Section</b>	<b>Radius (m)</b>	<b>PH</b>	<b>PK-TANK</b>	<b>PH-APC</b>
Inner Circle	25	0.9	0.3	0.6
Intermediate Circle	45	0.65	0.25	0.50
Max. Search Circle	75	0.50	0.2	0.40

False targets were not taken into account because information about that phenomenon was not available.

## **2. Simulation Output**

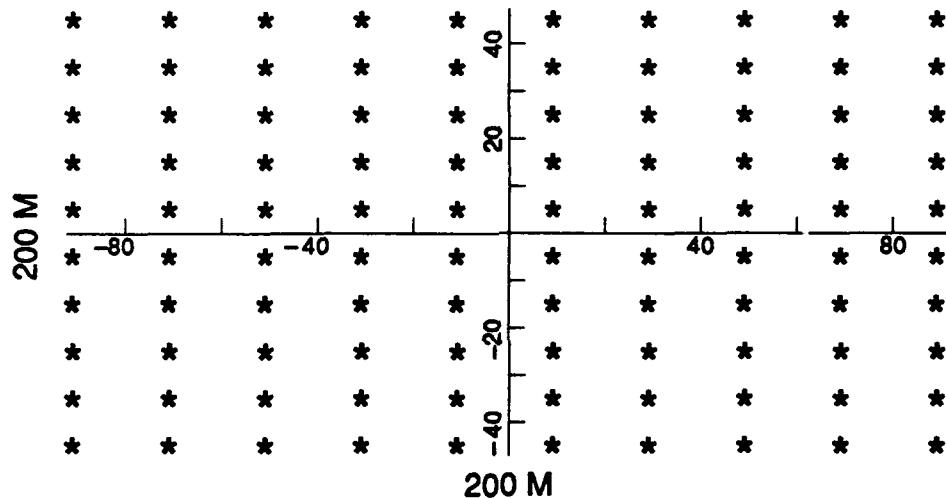
The programs were run on the mainframe computer (IBM 3033), controlled by exec programs. The number of rounds in the salvo were incremented after each simulation inside the main program, going from minimal to maximal relevant salvo size. The output file is a matrix in which the first row contains the salvo size and the other rows contain the simulation results. The results were analyzed by a GRAFSTAT software package and are presented in the next chapter.

### **III. TARGET DAMAGE ASSESSMENT**

#### **A. TARGET DESCRIPTIONS AND RESULTS**

The tools that were developed in the last chapter were implemented to assess damage to some typical targets.

##### **1. Target Number 1: Uniform And Homogeneous Density—Troops**



**Figure 5. Target No.1**

##### **a. Description:**

Object: Personnel

Number of units: 100

Target area size (m): 200(width)x200(depth)

Positions:

1.1 Standing

1.2 Prone

- 1.3 Position change during salvo: Initially troops are standing; then all are prone or entering into top open shelters. "Prone function" is an exponentially decaying function (rate = 60 seconds).

Target location error (one standard deviation):

Intelligence quality:

Good:	25 (m)
Regular:	50 (m)
Fair:	100 (m)

Ammunition type: Cluster bomblet warhead (or projectile)

**b. Results of 1.1 and 1.2**

The simulation results for target number 1 standing troops and marginal costs are shown in Figures 6 and 7, with TLE = 0, 25, 50, 100. The simulation results for target number 1 prone troops and marginal cost are shown in Figures 8 and 9, with TLE = 0, 25, 50, 100.

The following results can be observed from the figures:

1. The more accurate the weapon, the more sensitive it is to TLE.
2. When high target damage is required, sensitivity to TLE increases.
3. Tube artillery is usually less expensive, but the rate of kill is extremely low (divide the number of rounds by the rate of fire—three rounds per minute). In practice, more than one gun should fire at the same target.
4. MARS tends to be relatively more effective when the TLE is large (more than 100 m). However, when the TLE is higher than 100, all results are poor.
5. TCAR is much superior to the other two systems, having a high rate of kill and a capability of achieving a high damage level, but with a slightly higher cost than the G155.

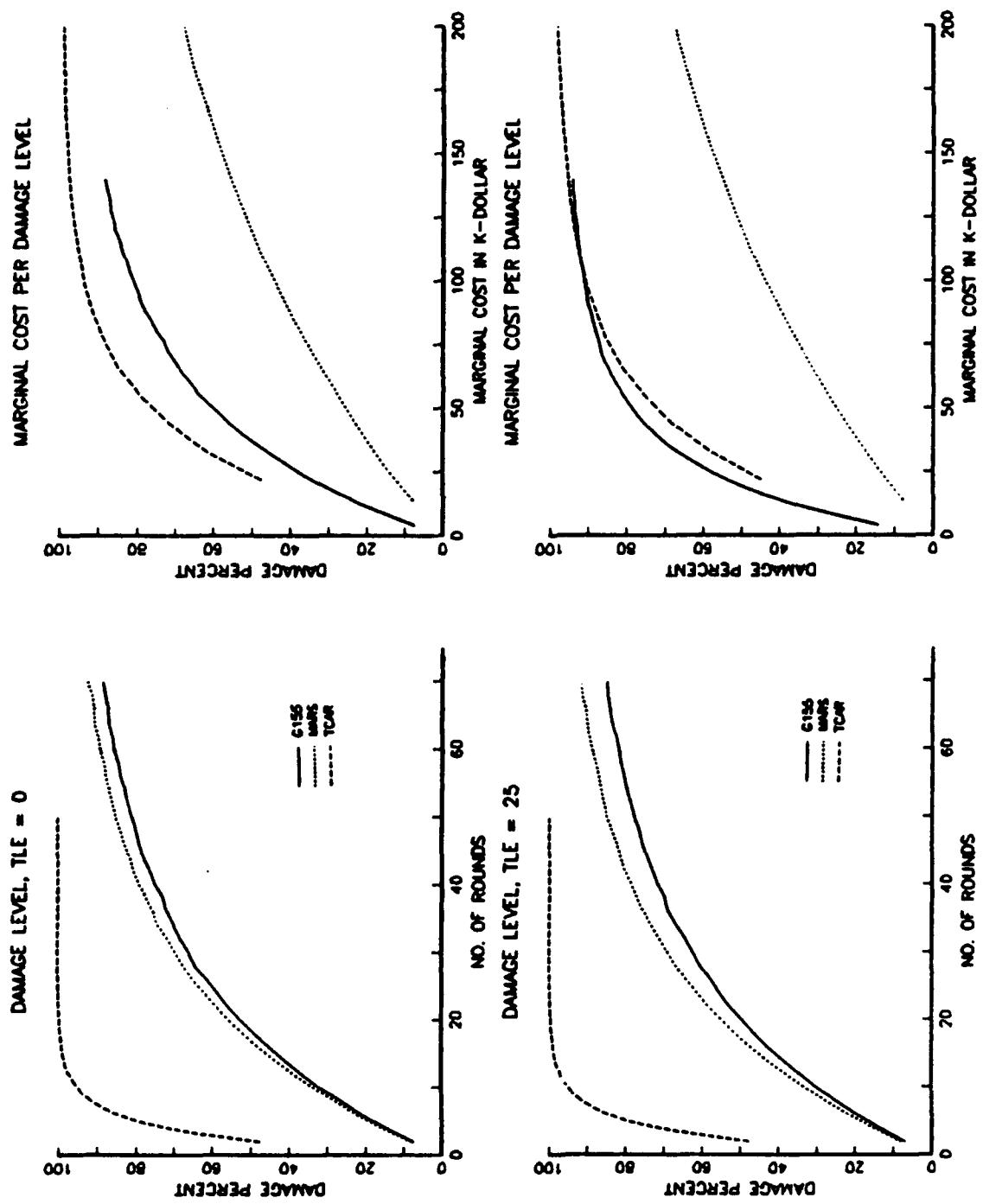


Figure 6. Target No. 1, Standing Troops

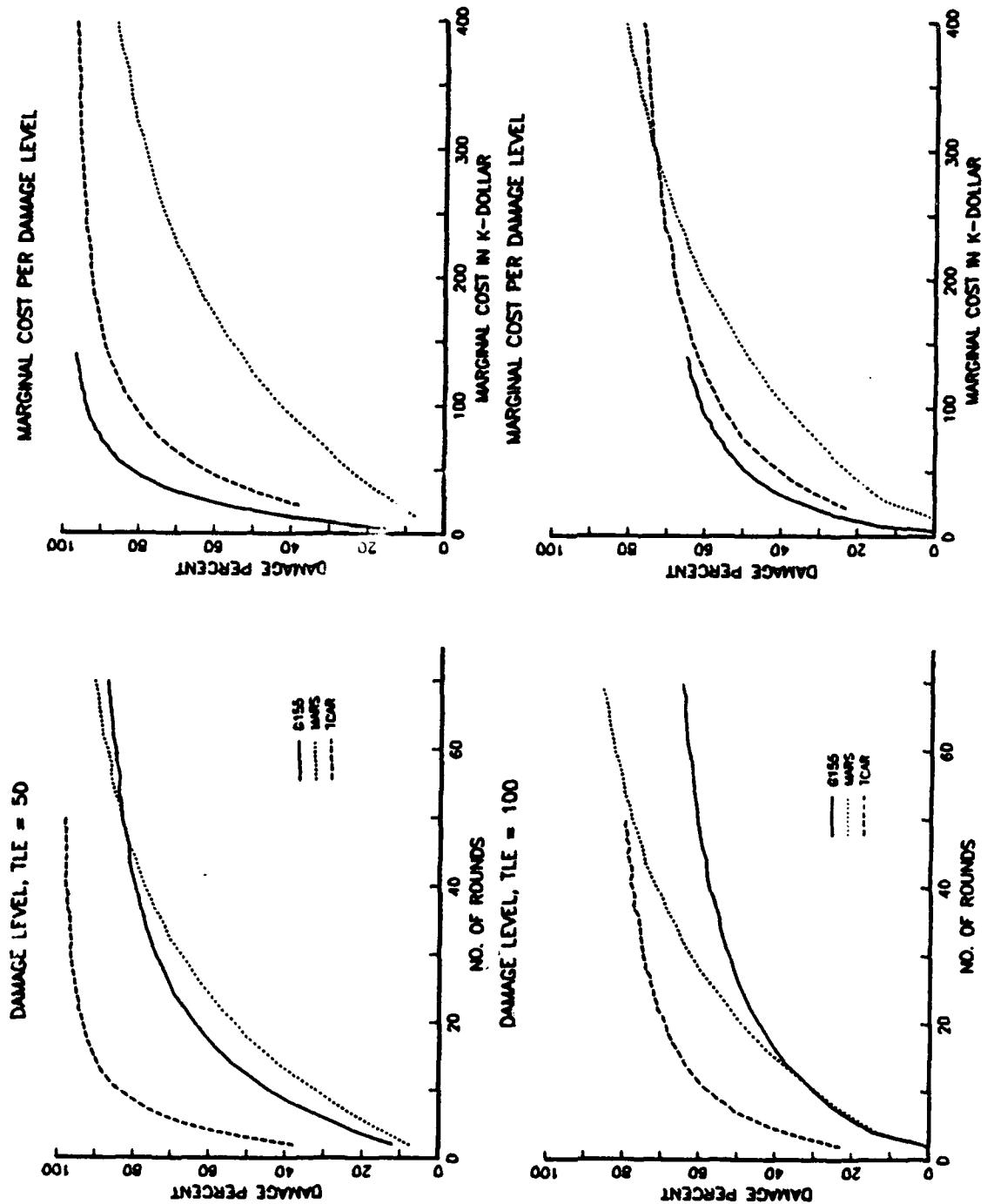


Figure 7. Target No. 1, Standing Troops

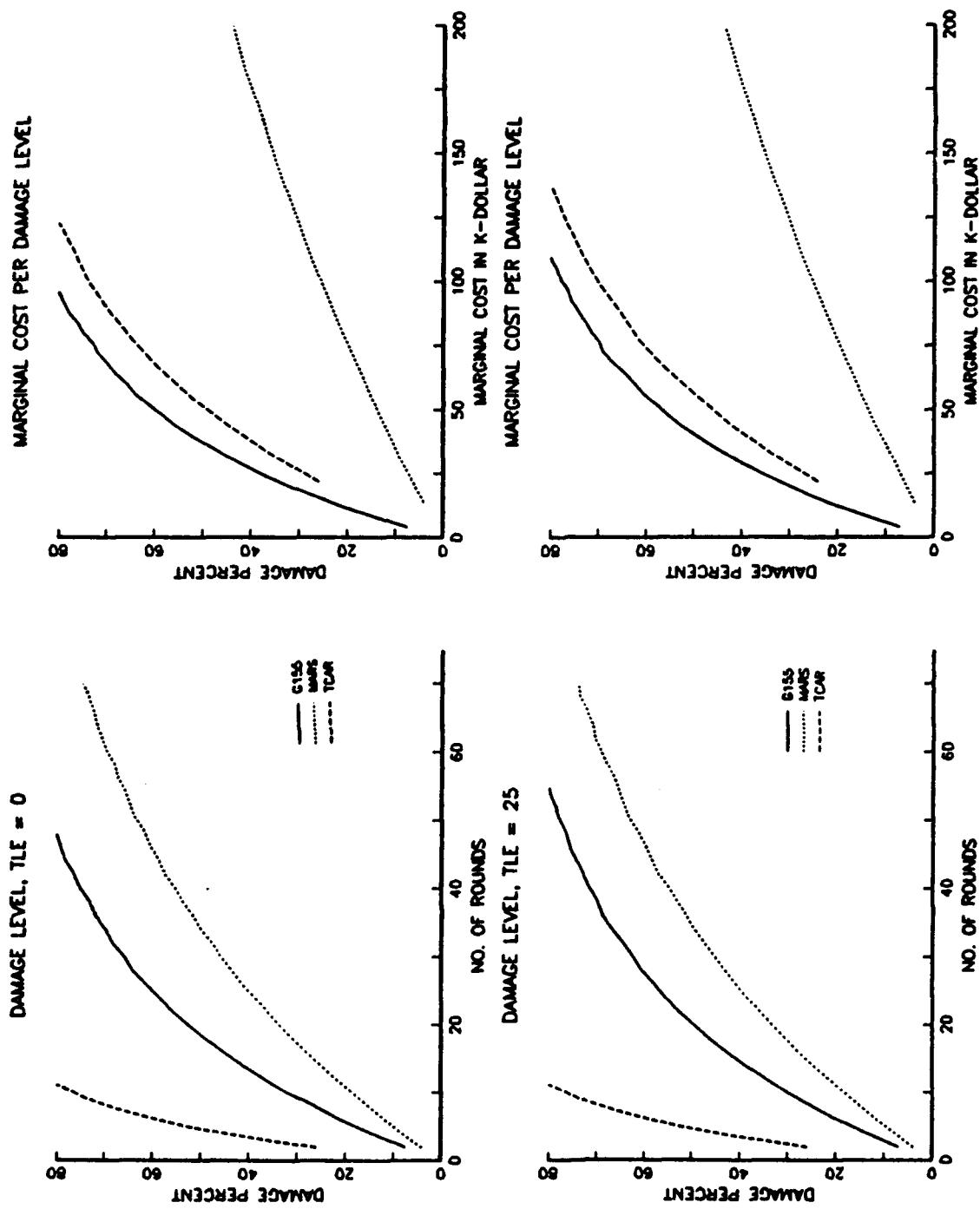


Figure 8. Target No. 1. Prone Troops

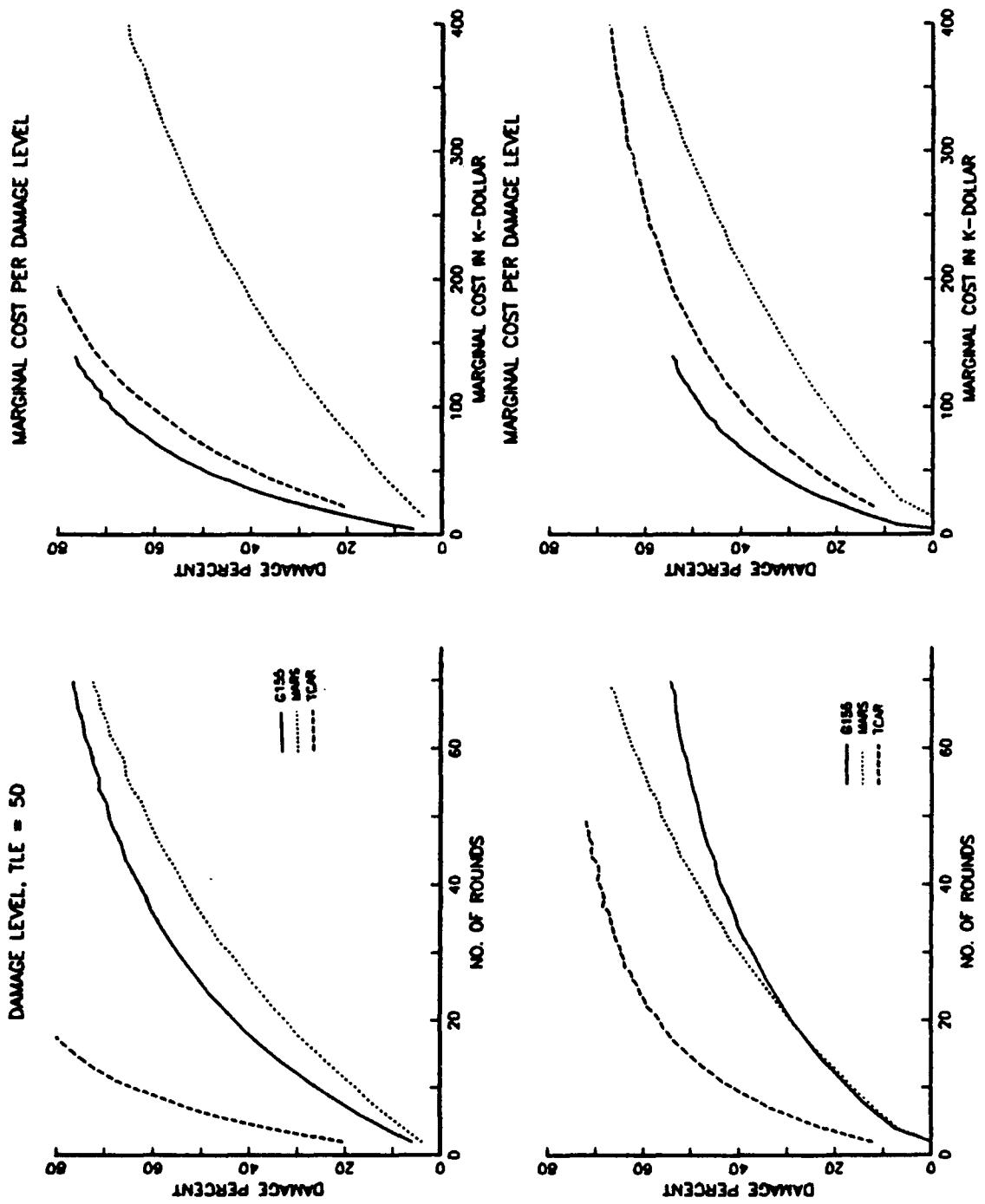


Figure 9. Target No. 1. Prone Troops

**c. *Simulation of a Troop Target That Changes Position During Salvo***

Troops find shelter in trenches during a salvo (the rate of finding shelters is 60 seconds). The lethal area of one bomblet when troops are in shelters is one square meter. Figure 10 shows the simulation results.

This case illustrates the degradation of the effectiveness of tube artillery when it is necessary to produce massive fire power on a target. The massive fire power is essential because the objects will probably not stay in place.

These results show that one rocket launcher is capable of producing the same amount of target damage as six guns (maximum 49 percent damage). When firing units on the battlefield are scarce, artillery rocket systems are advantageous, but the cost is high.

Again, the TCAR is far superior to the other systems (maximum 74 percent after 10 rounds).

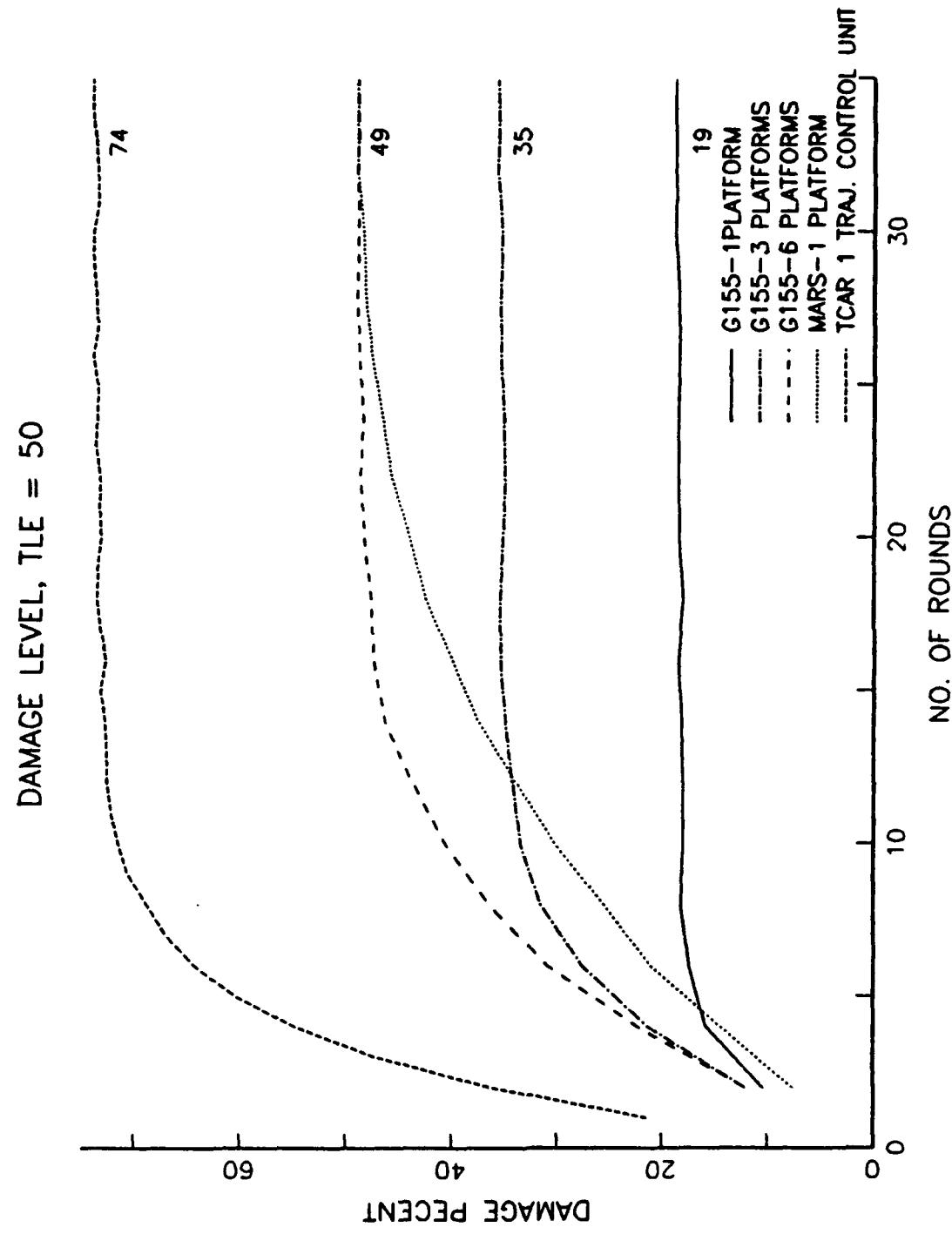
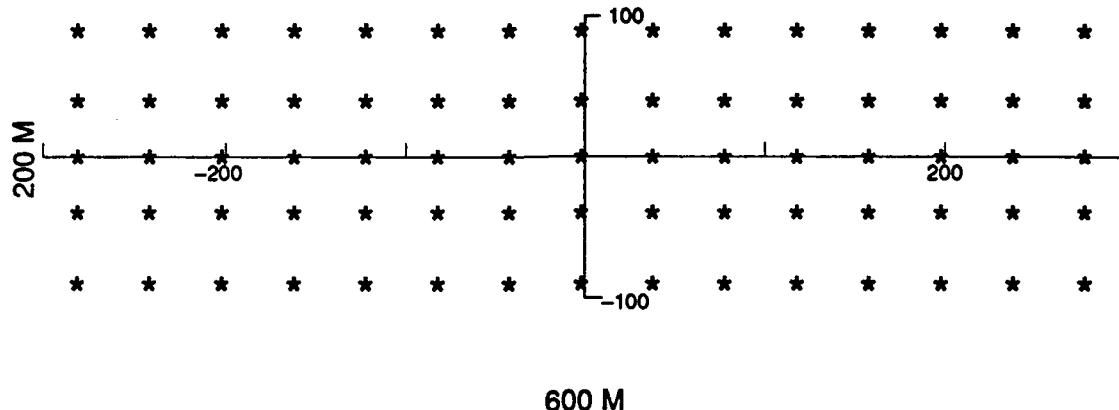


Figure 10. Target No. 1. Standing Troops Finding Shelters

## **2. Target Number 2: Troops in an Open Area, Nonsymmetrical Homogeneous Target**



**Figure 11. Target No. 2**

### **a. Description:**

Object: Personnel

Number of units: 75

Target area size (m): 600 (width) x 200 (depth)

Position: Standing, prone

Target location error (one standard deviation):

Intelligence quality:

Regular: 50 (m)

Ammunition type: Cluster bomblet warhead (or projectile)

### **b. Results**

Target number 2 is a "wide" area target, so the target was divided into sections and the aiming point for each was determined. This split in aiming was done by the function SPLIT, which allocates a number of rounds to each section proportionally. The figures were rounded to

integers by putting a "floor" on the outer sections and a "ceiling" on the inner sections.

The simulation results of target number 2 for standing troops and marginal costs are shown in Figure 12, with TLE = 0, 50. Figure 13 shows the results for prone troops.

Aiming points deviations in x direction are:

155 How. gun (m):      75, -75, 225, -225

LAR160 and TCAR (m):  0, 200, -200

The following results can be observed from the figures:

1. Tube artillery is the most cost-effective, but rate of kill is poor.
2. The artillery rocket is the least cost-effective, but the rate of kill is high—it needed the same number of rounds as the gun, but the rate of fire is 12 times faster.
3. TCAR has a much higher rate of kill. It is less cost-effective than guns, but a much higher damage level can be achieved.
4. Results are less sensitive to TLE (intuitively it is explained by the width of the target).

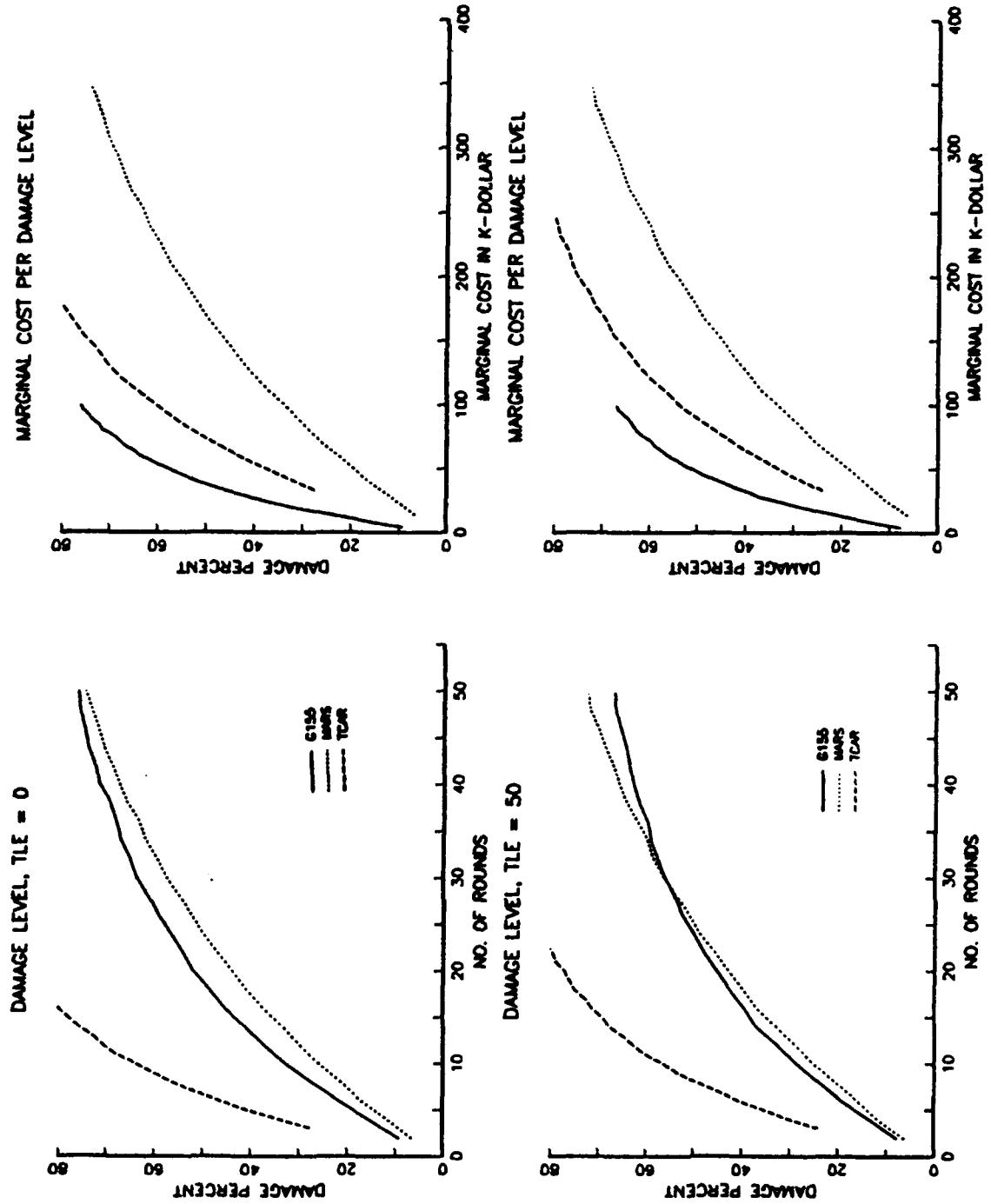


Figure 12. Target No. 2, Standing Troops

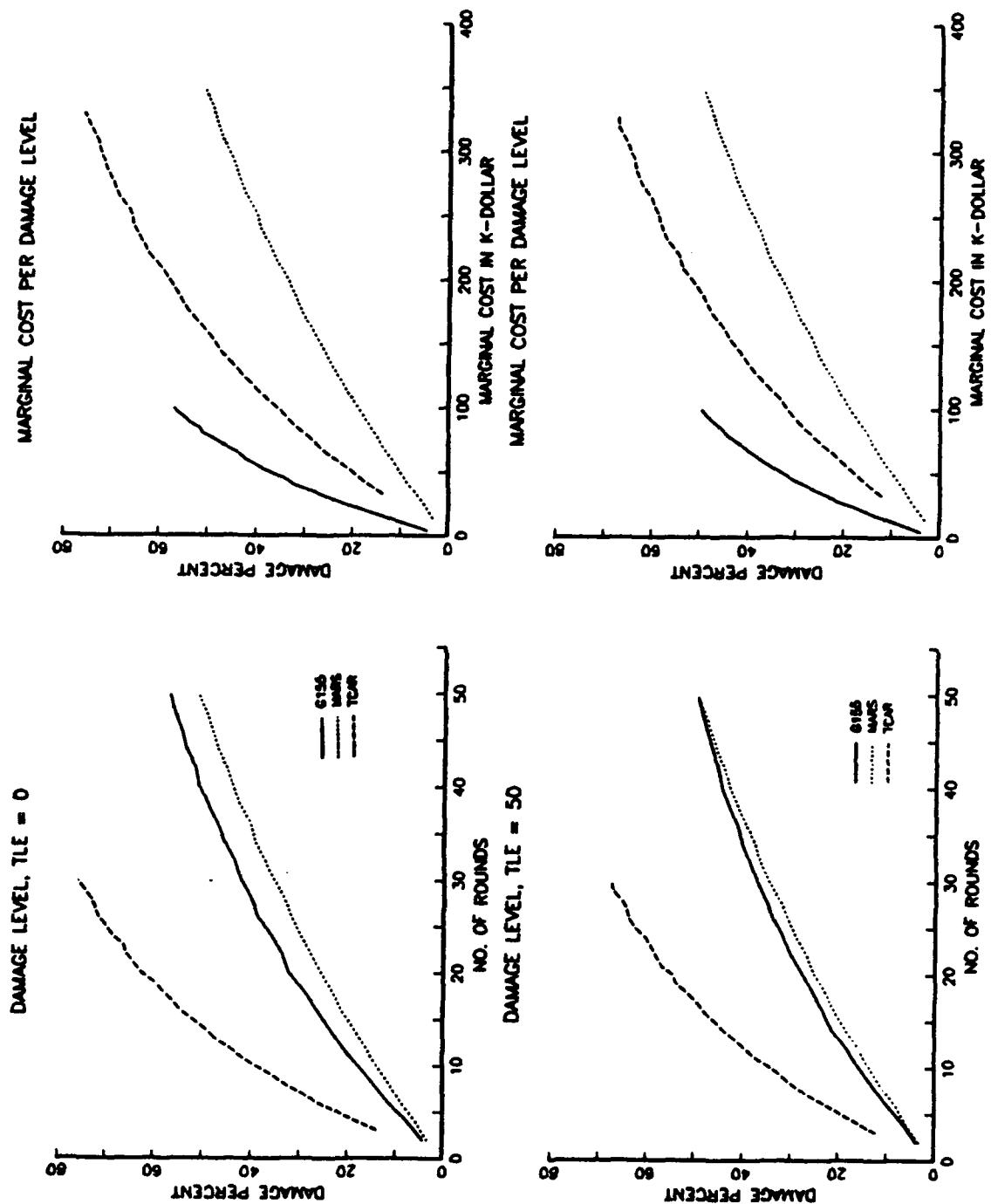
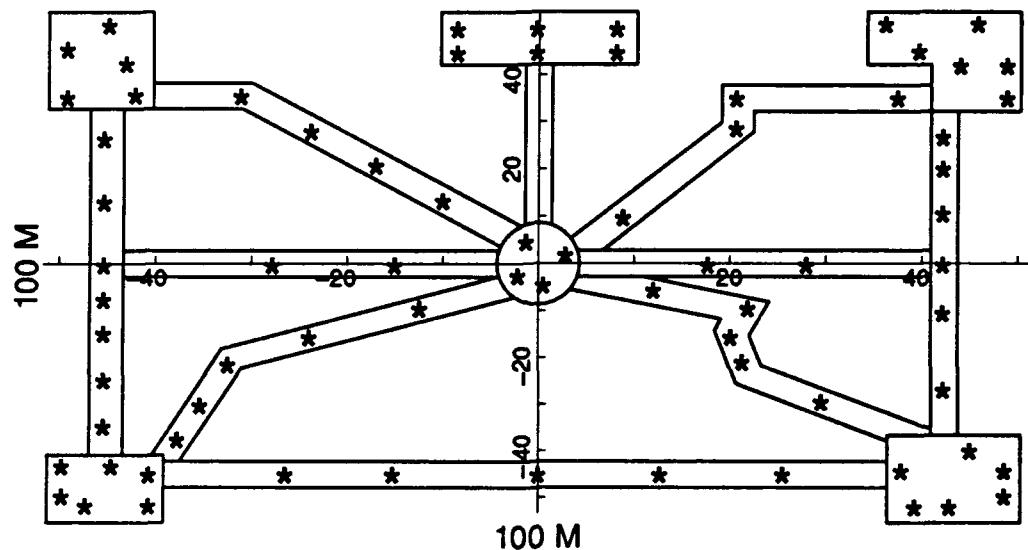


Figure 13. Target No. 2, Prone Troops

### **3. Target Number 3: Troops in a Company at a Defense Site**



**Figure 14. Target No. 3**

#### **a. Description**

Object: Personnel

Number of units: 76

Target area size (m): 100 (width) x 100 (depth)

Position: Troops in open excavations

Target location error (one standard deviation):

Intelligence quality:

Regular: 50 (m)

Ammunition type: Cluster bomblet warhead (or projectile)

Figure 15 shows the results.

#### **b. Results**

The following results can be observed from the figures:

1. The relations between system performances are the same as before.

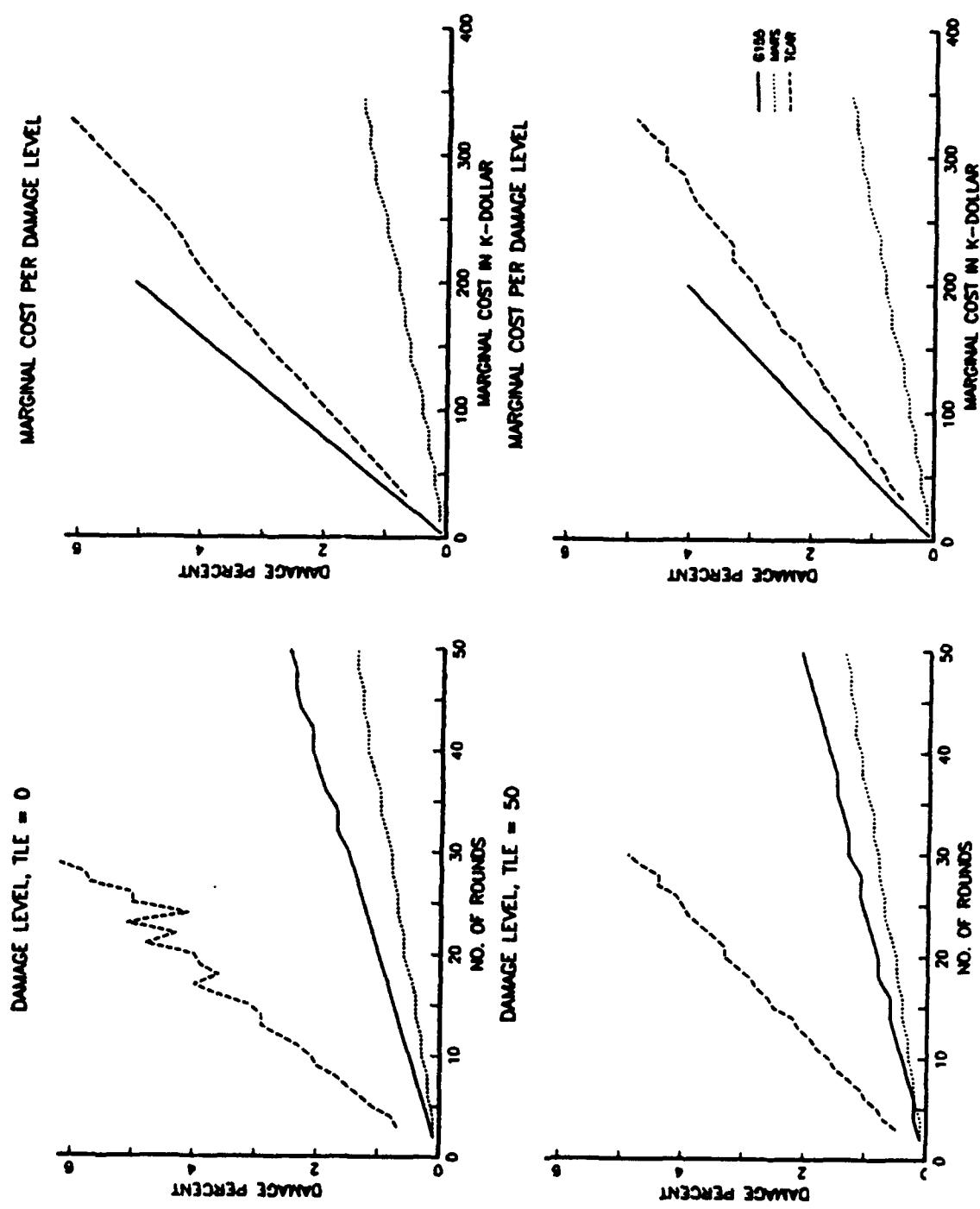


Figure 15. Target No. 3, Troops in Open Shelters

2. All results are very poor—at most six percent damage. Consequently, the cluster bomblet as a submunition is not effective against fortified targets.

We might get better results if we used a greater number of smaller bomblets (M77) in the warheads.

#### 4. Target Number 4: Self-Propelled Armored Howitzer Gun Battery in Firing Deployment

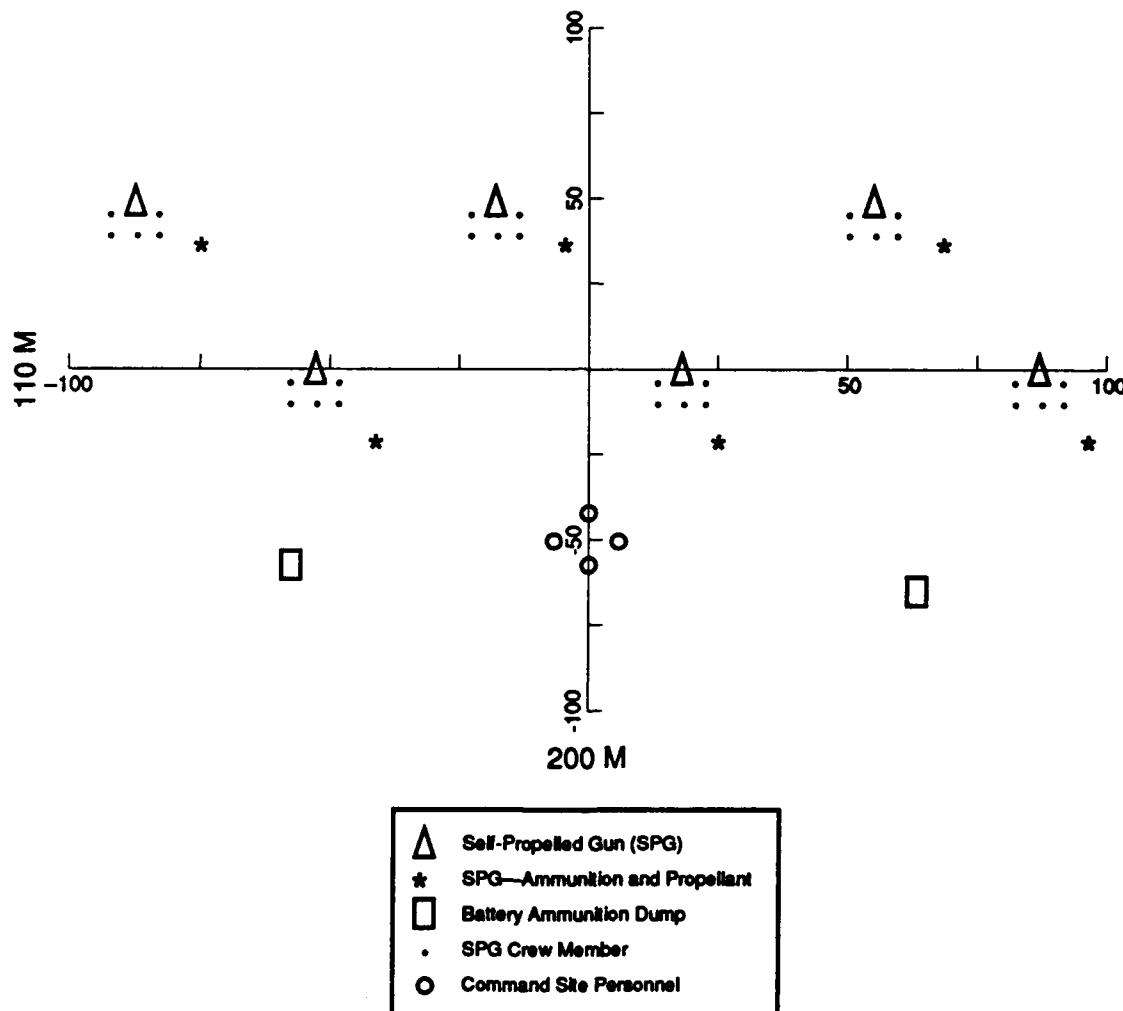


Figure 16. Target No. 4

**a. Description**

Objects:	Number of Units:
1.1 Armored self-propelled guns	6
1.2 Guns ammunition and propellant piles	6
1.3 Crew members (standing around the gun)	5 x 6
1.4 Battery command site (crouching personnel)	4
1.5 Battery ammunition dump in cases	2

Target area size (m): 200 (width) x 100 (depth)

SPG: "W"-shaped deployment with command post at the center

Ammunition: Beside each SPG, two battery dumps

Target location error (one standard deviation):

Intelligence quality:

Regular 50 (m)

Ammunition type: Cluster bomblet warhead (or projectile)

The following assumptions are made:

1. Only a direct bomblet hit on ammunition or propellant, in cases or in the open, causes detonation. Therefore, the vulnerable area of the ammunition dumps is taken as their base area.  
For gun ammunition and propellant piles— 16 sqm.  
For battery ammunition dump in cases— 36 sqm.
2. The lethal area of SPG when hit by a bomblet is low. However, it is more practical to use the neutralization area instead. It is sufficient to break down one subsystem inside the SPG in order to stop it from functioning. This area was taken as 10 sqm.
3. A crew is considered to be standing troops. Command site personnel are considered to be crouching troops and the lethal area is assumed to be 100 sqm.

**b. Results**

Simulation results on gun crew members and command site are shown in Figure 17. Results for the SPGs, gun ammunition, and propellant piles and battery ammunition dump are shown in Figure 18. Marginal costs for the last three are given in Figure 19.

The target is "wide", so two aiming points were chosen:

Deviations in X direction are: +50 m, -50 m

The following results can be observed from the figures:

1. Results for the crews of SPG and command sites show similar behaviors as before. It is important to note that only a few TCAR rounds are needed to destroy the command post crew, resulting in neutralization of the whole battery.
2. TCAR is superior to the other two systems, with a very high killing rate (see Figure 18, all three objects).
3. Guns are the most cost-effective, but they achieve only a limited destruction probability due to their low rate of fire.
4. The probability of detonating ammunition is significant. Such an event causes fatal results and significantly damages guns and crews. Therefore, it is apparent that a cluster weapon is effective as a counterfire weapon. If delivered by TCAR, it is extremely effective.

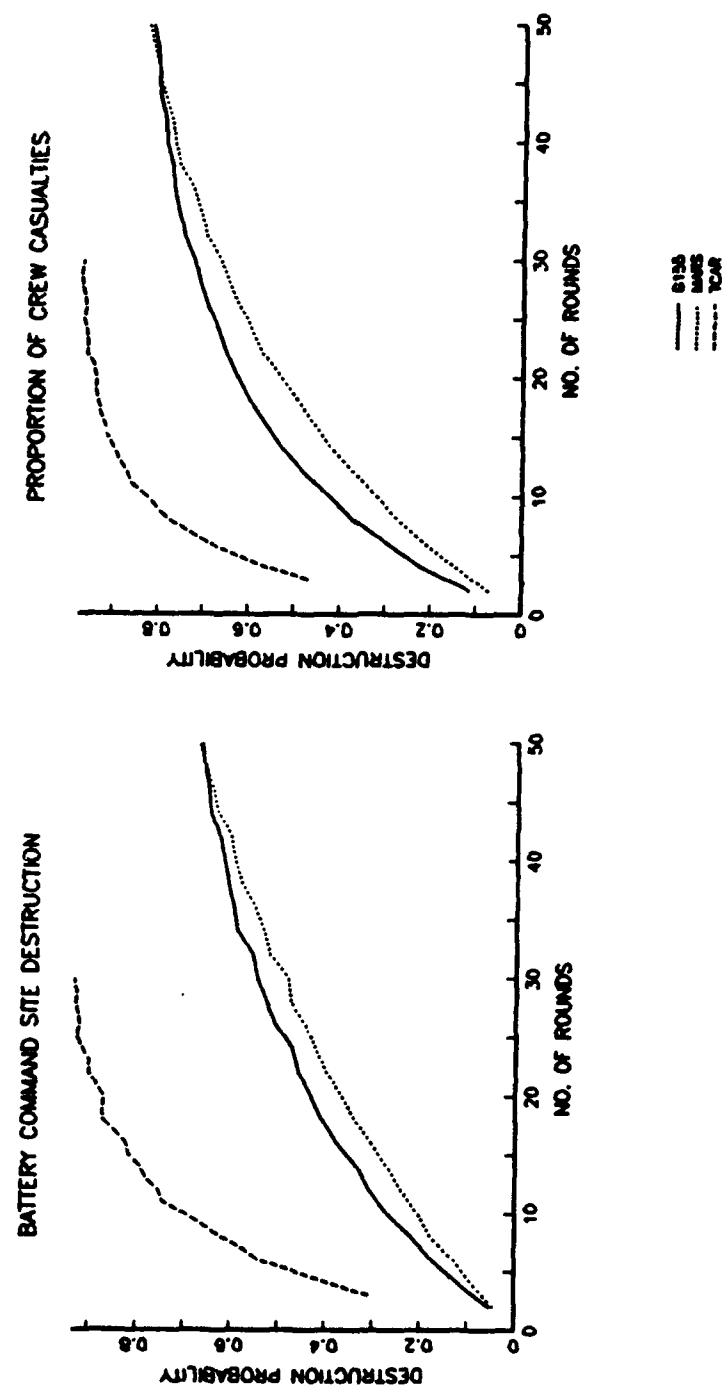


Figure 17. Target No. 4, Artillery Gun Battery, TLE = 50

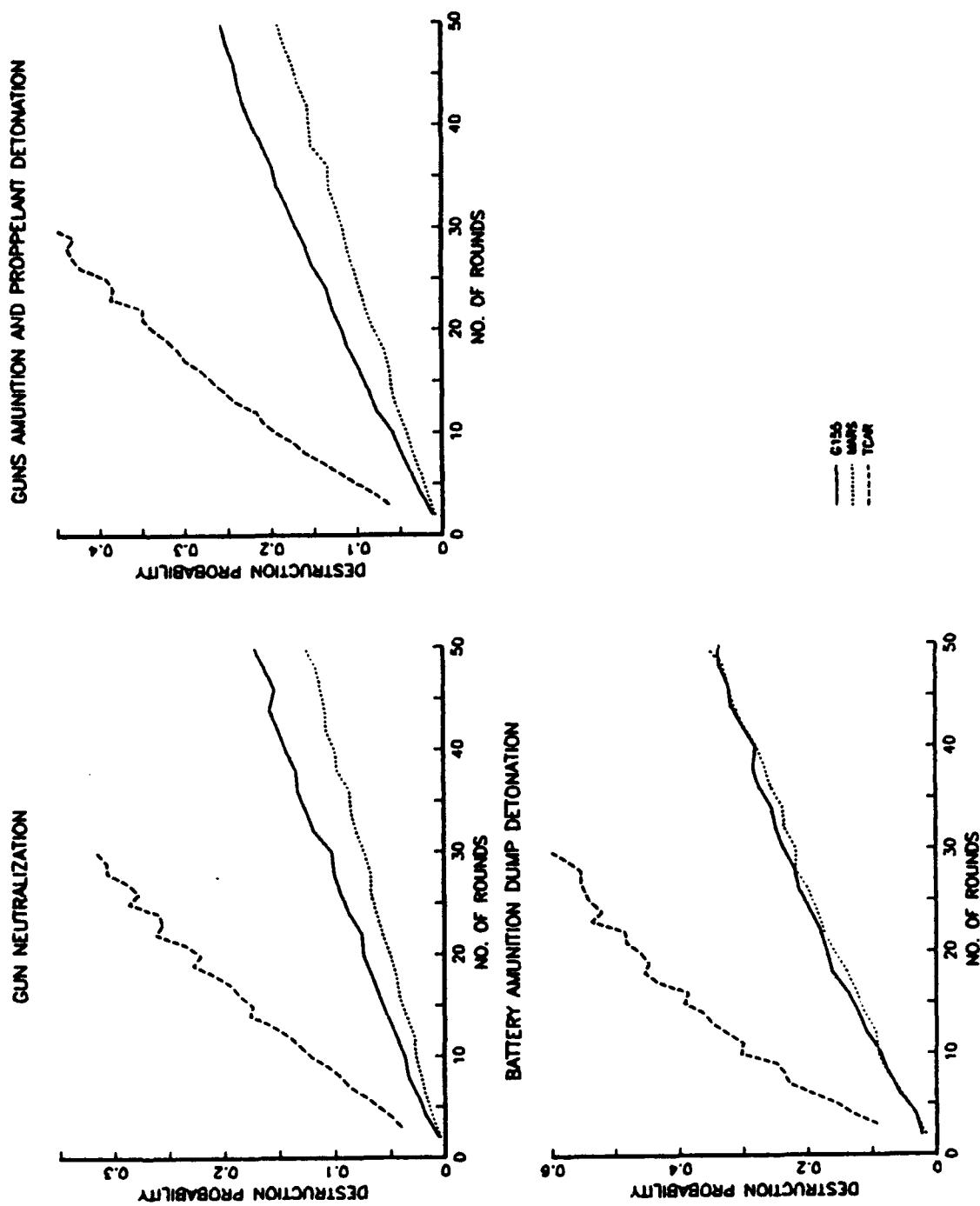


Figure 18. Target No. 4, Artillery Gun Battery, TLE = 50

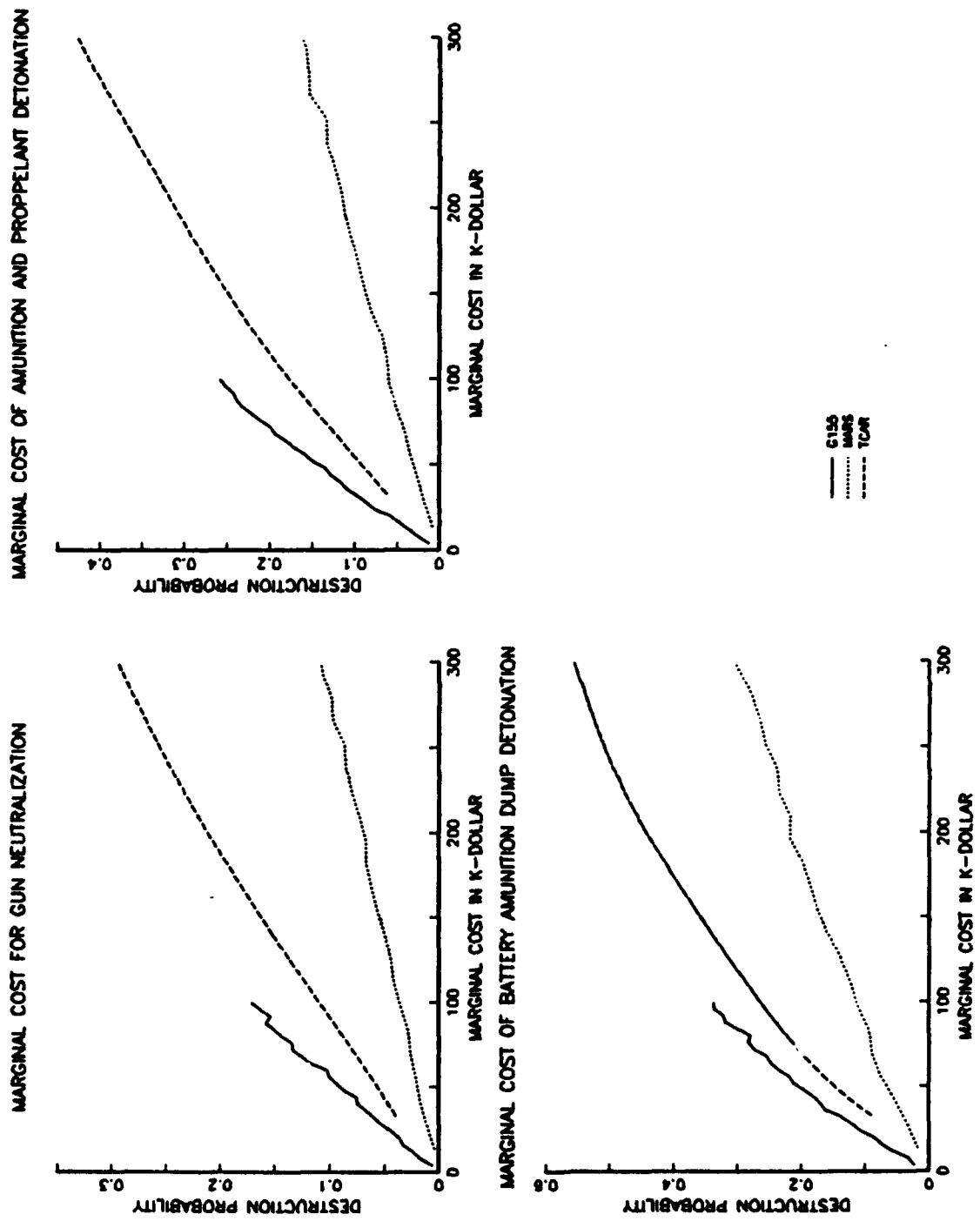


Figure 19. Target No. 4, Artillery Gun Battery. TLE = 50

## 5. Target Number 5: Soft Vehicles, Logistic Convoy

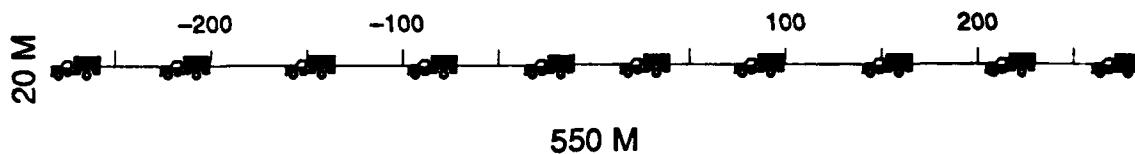


Figure 20. Target No. 5

### a. Description

Object: Soft vehicles, trucks carrying troops

Number of units: 10, each carrying 8 troops

Target area size (m): 600 (width) x 25 (depth)

Position: On road, heading X direction

Target location error (one standard deviation):

Standing line and good intelligence 25 (m)

On the move and good intelligence 250 (m) along the road  
25 (m) across the road

Passengers are sitting in the trucks, two in the cabin, six in two rows—at the cargo platforms, on two parallel benches.

Ammunition type: Cluster bomblet warhead (or projectile)

Supplementary data:

1. Trucks lethal area—20 sqm

2. Passengers, in sitting position—100 sqm. They are partially protected by the truck, but they are sitting high above ground level.

### b. Results

Figure 21 shows the simulation results and marginal cost of damage to trucks and personnel, when the convoy is stationary.

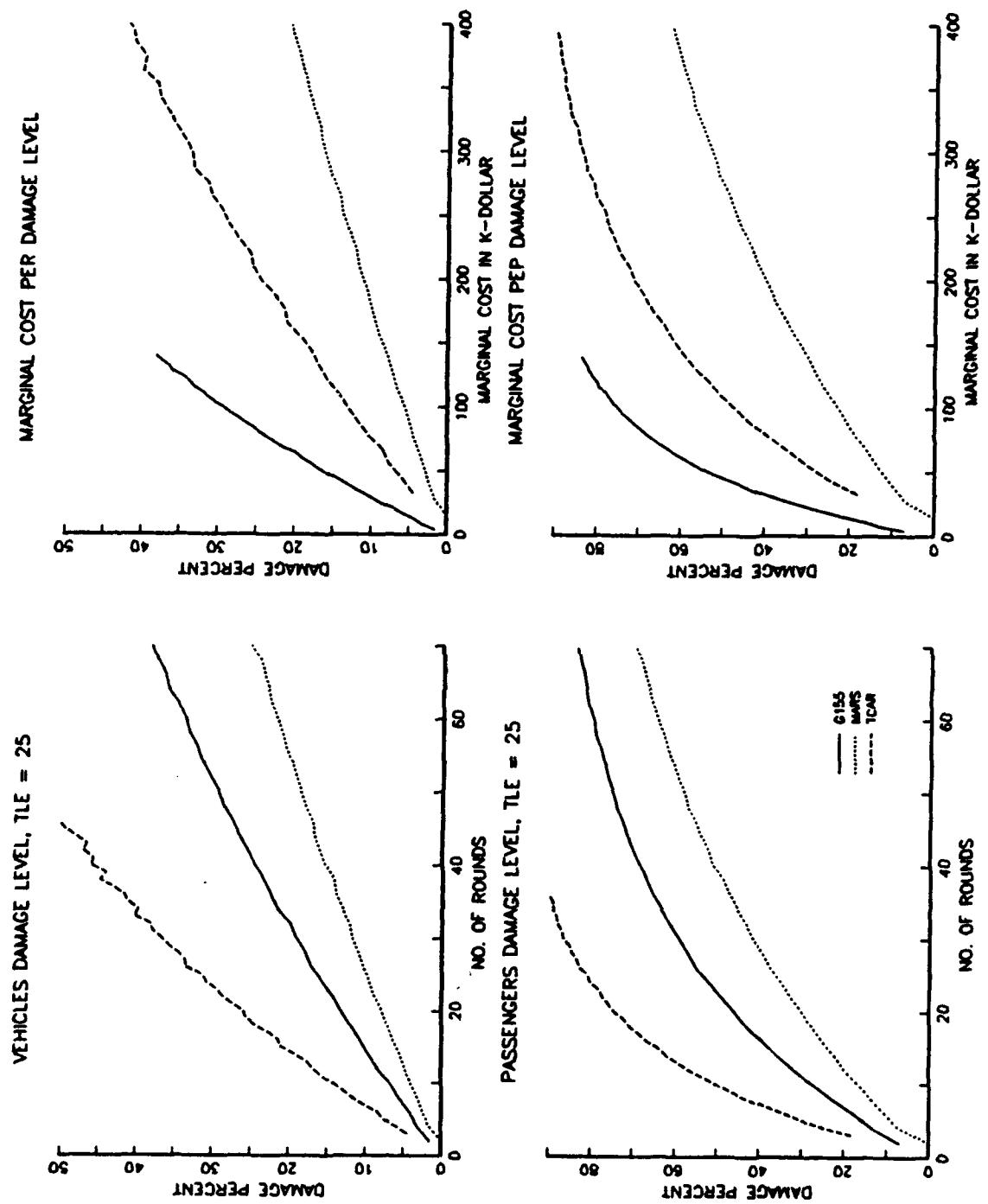


Figure 21. Target No. 5, Vehicle Convoy

**Figure 22 shows the simulation results when the convoy is on the move. The two right graphs show the progression of damage level over time.**

**The following results can be observed from the figures:**

1. When the target is stationary, we get results similar to those from previous targets. The highest killing rate is attributed to the TCAR; moreover, the G155 is the most cost-effective.
2. When the target is on the move, the rate of kill becomes a dominant factor. A comparison has been made with a firing battery of G155 (as well as a single gun). The right two graphs of Figure 18 show that all three systems can produce almost the same damage progression through time for both trucks and personnel. The G155 battery was found to be the most cost-effective. This depends on the availability of enough firing units in a busy arena to engage the target. If this is not the case, then the G155 is not effective at all.

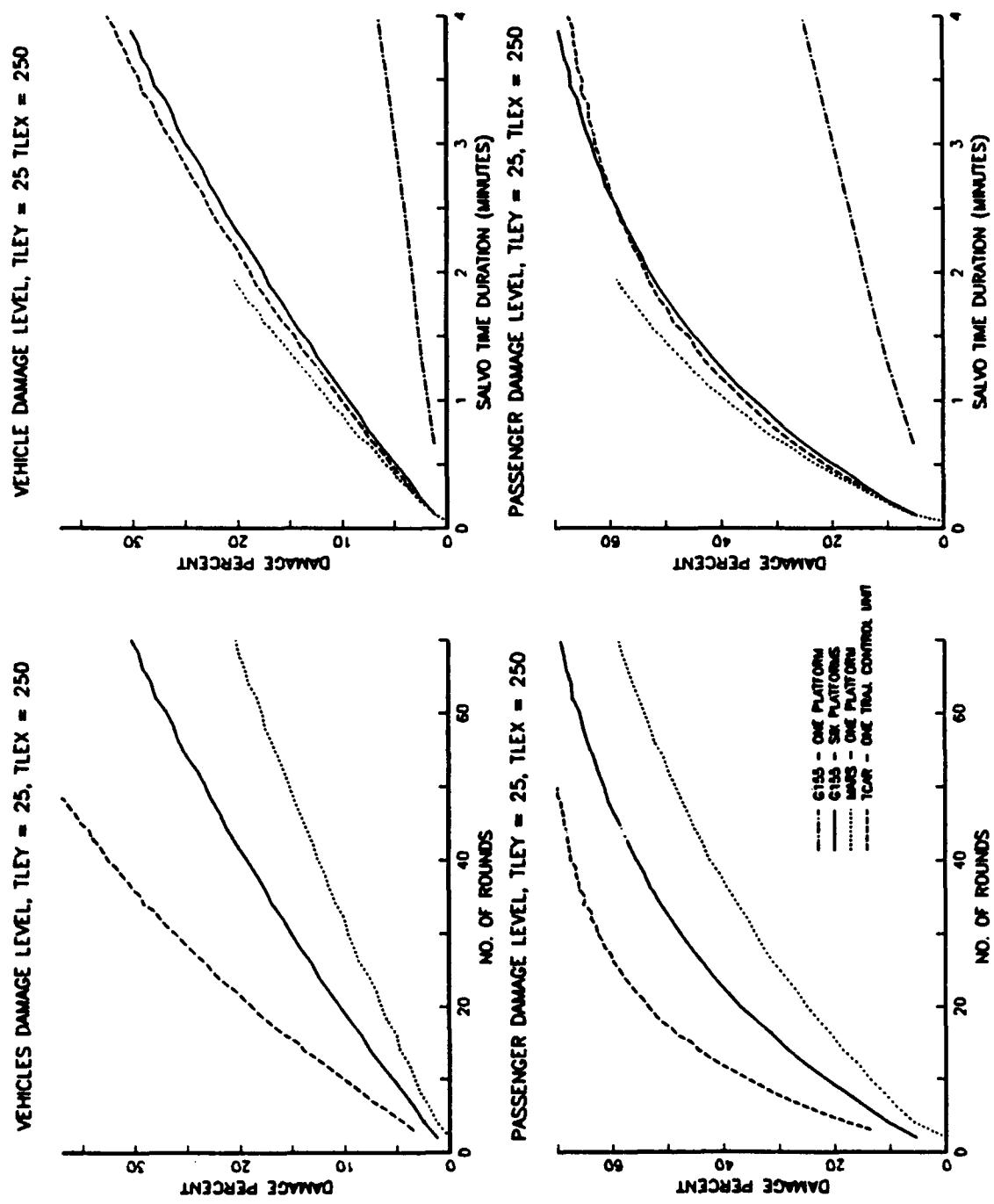


Figure 22. Target No. 5, Vehicle Convoy on the Move

## 6. Target Number 6: Mixed-Type Target In Defense Position

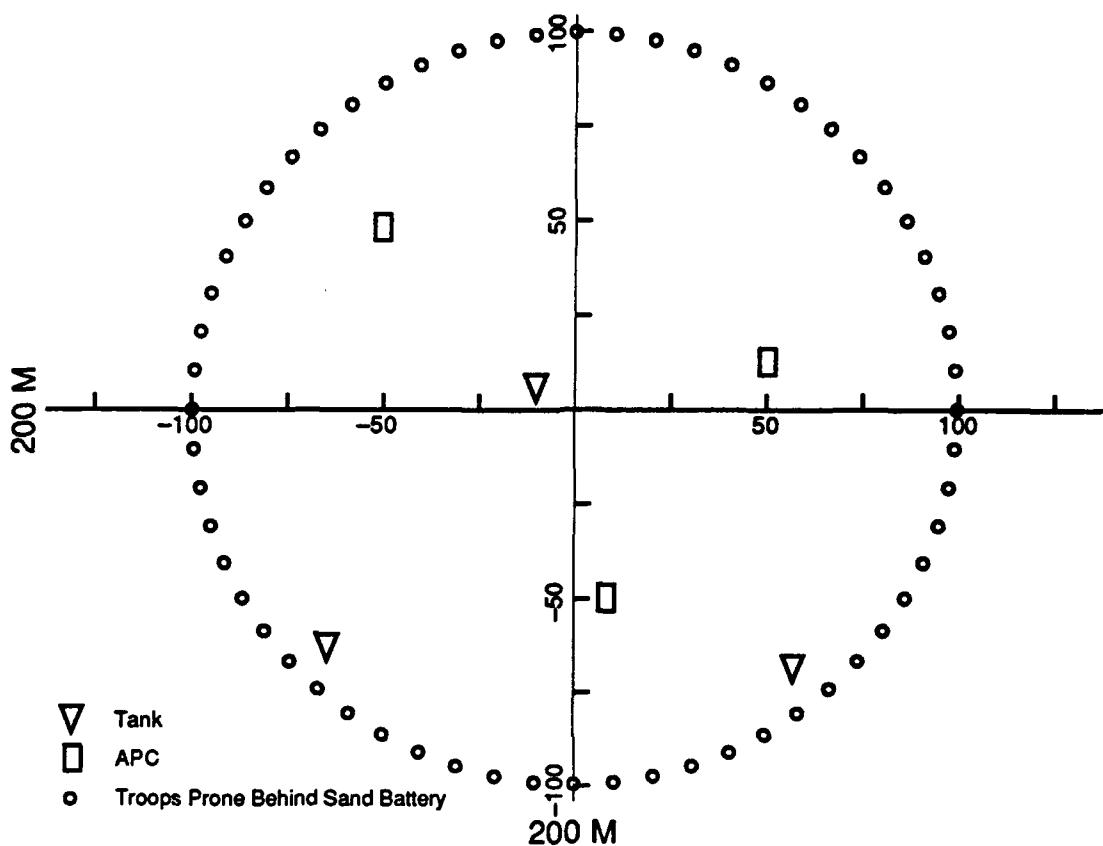


Figure 23. Target No. 6

### a. Description

Objects:	Number of Units:
Tanks	3
APCs	3
Personnel	60
Target area size (m):	100 m radius, round fortified site
Position:	Tanks and APCs in firing trenches; personnel are prone behind a sand battery surrounding the site.

Target location error (one standard deviation):

Intelligence quality:

Regular            50 m (This is a typically stationary target which is usually detected properly.)

Ammunition type:      Cluster bomblet warhead (or projectile)  
                          SFM submunition warhead (or projectile)

Supplementary data:

The lethal area for a troop lying behind a sand battery is approximately half that of prone in the open—40 sqm.

**b. Results**

Figure 24 shows simulation results and marginal costs of the damage level on tanks. Figure 25 shows the same on APCs. In both figures, the upper two graphs show results of simulations of the three systems that contain SFM submunition warheads. The lower graphs show the same with cluster bomblet warheads.

The following results can be observed from the figures:

1. Rates of kill with SFM submunitions (upper-left graphs) are high for the three systems. TCAR is far superior to the others. MARS and G155 are similar in damage per number of rounds, which means the rate of kill of the MARS is much higher than that of the G155 (because the firing rate of the MARS is much higher).
2. Rates of kill with cluster bomblet warheads (lower-left graphs) show low results for TCAR and poor results for the others.
3. Cost-effectiveness with SFM submunitions (upper-right graphs): TCAR is the most cost-effective, significantly higher than the G155. MARS yields very poor results.
4. There is not much difference in cost-effectiveness between the cluster warheads and the SFM warheads, but the comparison is made at a low level of damage (the ordinates scales represent number of destroyed tanks/APCs). Note that the cluster weapon cannot achieve the same high levels of damage as the SFM within a reasonable time.

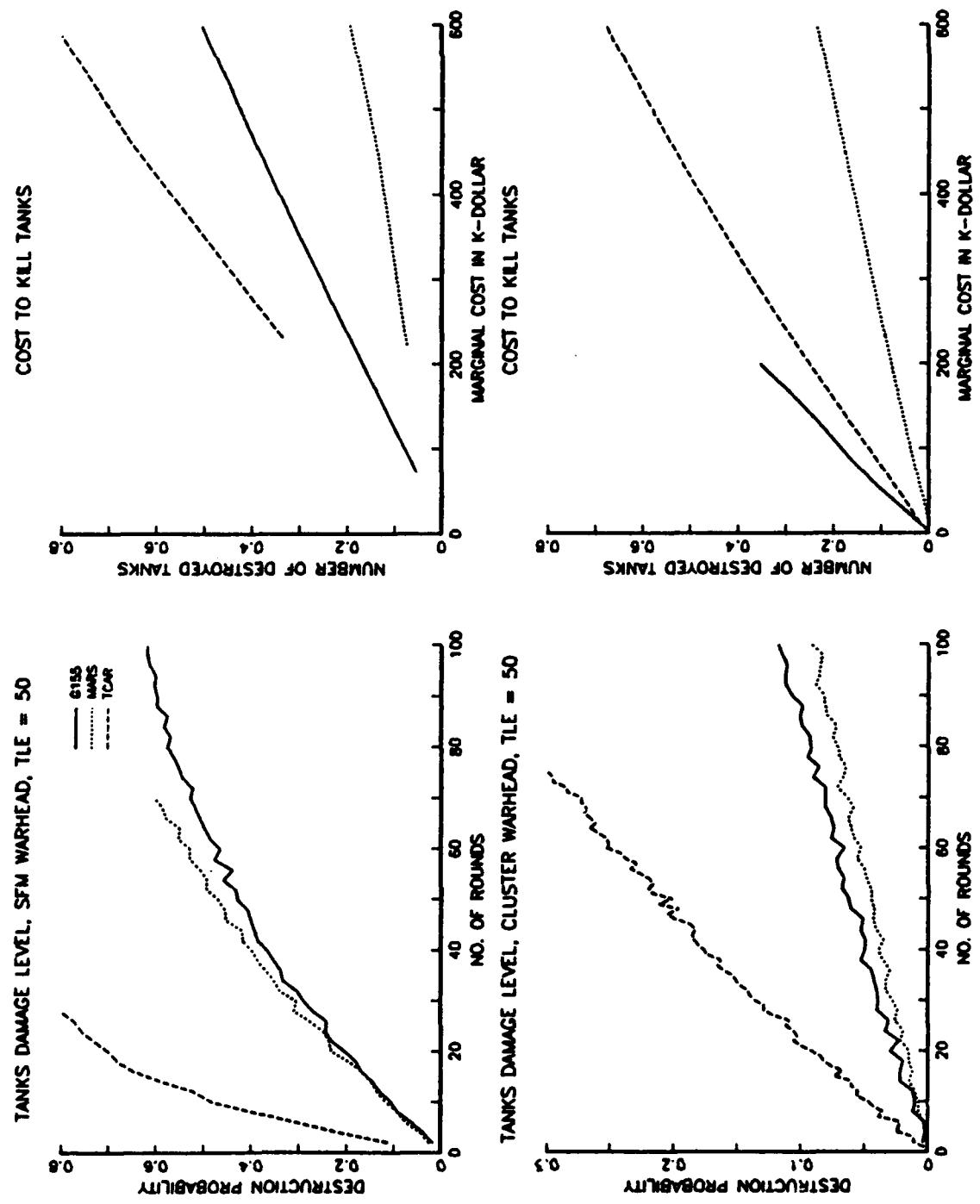


Figure 24. Target No. 6, Tanks, SFM vs. Cluster Warheads

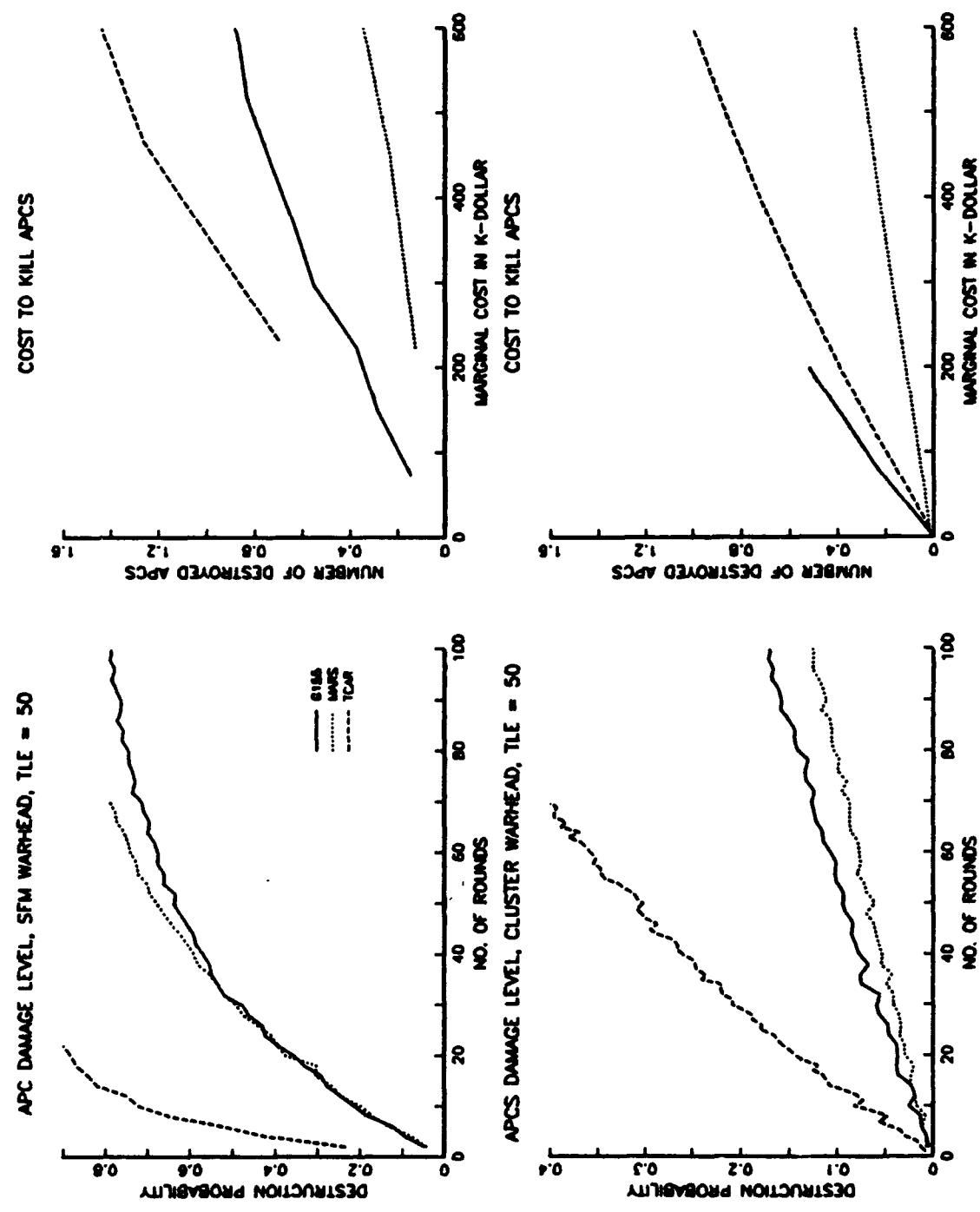


Figure 25. Target No. 6, APCs, SFM vs. Cluster Warheads

5. SFM submunitions: the cost to kill the first tank with TCAR is \$770,000 (\$348,000—APC); with G155 it is \$1,250,000 (\$666,000—APC) and with MARS is \$3,584,000 (\$2,016,000—APC).

Remarks:

- a. The above is not represented in the graphs.
- b. The first tank to be destroyed, on average, cannot be achieved with a cluster bomblet weapon within a reasonable number of rounds.
6. The cost to kill the second tank with TCAR is \$1,318,000; doing so with MARS or with G155 is not reasonably achievable.
7. The cost of killing the first armored vehicle (tank/APC) with TCAR is \$232,000. This is a better measure of cost because the effectiveness of the system against tanks depends on the existence of APCs in the target area. If an SFM submunition attacked an APC, it would not be available to attack a tank. In terms of effectiveness against tanks only, this particular submunition is wasteful.

The first armored vehicle for G155 would cost \$407,000 and for MARS would be \$1,120,000.

Troops: The results for prone troops in the target yield similar relationships between the systems as before, so results are not shown on the graphs.

## 7. Target Number 7: Armor in an Offensive Site

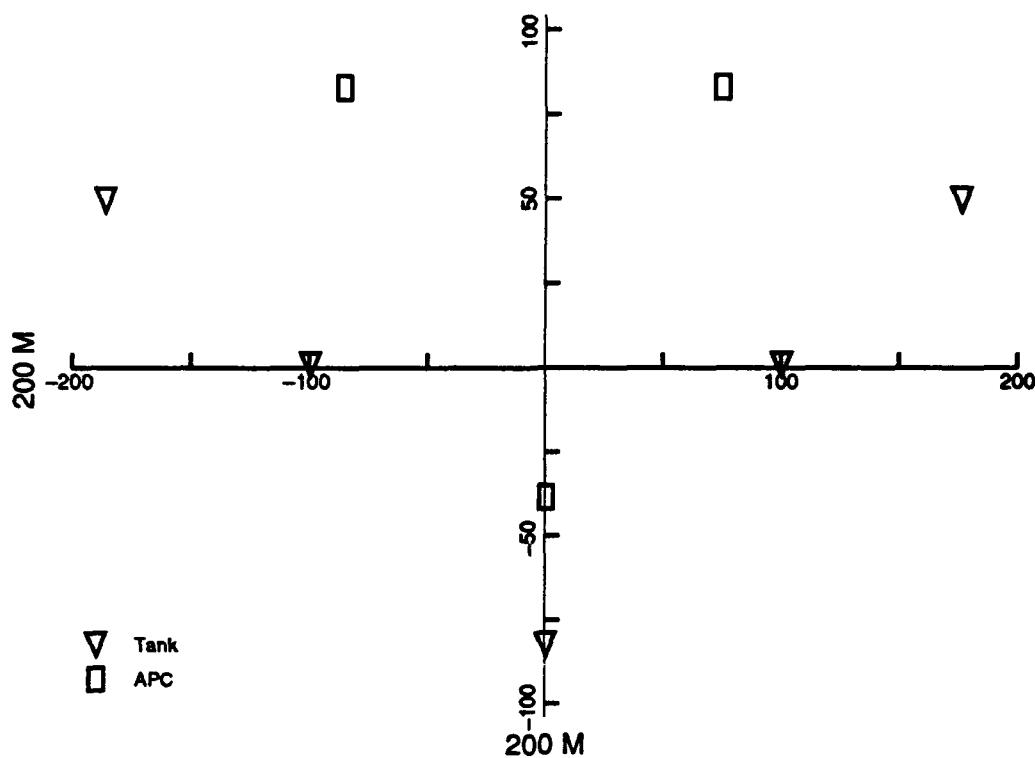


Figure 26. Target No. 7, Armor in an Offensive Site

### a. Description

Objects: Number of Units:

Tanks	5
APC	3

Target area size (m): 360 (width) x 160 (depth)

Position: Tanks and APCs in firing sites

Target location error (one standard deviation):

Intelligence quality

Regular	50 m
---------	------

Ammunition type: SFM submunition warhead (or projectile)  
Aimpoints were shifted to achieve the best results for each system.

**b. Results**

Figure 27 shows simulation results and marginal costs of the damage level on tanks and APCs.

The following results can be observed from the figures:

1. The two upper graphs of Figure 27 are for tanks. The lower graphs are for APCs. The difference in the line curvatures can be explained as a result of having only three APC units vs. five tanks. The marginal effectiveness and cost decrease as the remaining number of live targets becomes small.
2. TCAR has a far higher advantage over the other two systems in kill rate. G155 has an extremely low kill rate.
3. TCAR has the best cost-effectiveness for tanks and equal cost-effectiveness compared to G155 for APCs.
4. The cost to kill the first tank with TCAR is \$928,000 (\$694,000—APC), with G155 is \$1,665,000 (592,000—APC), and with MARS is \$4,032,000 (\$1,792,000—APC).
5. The cost to kill the first armored vehicle (tank/APC) with TCAR is \$348,000, with G155 \$407,000, and with MARS \$1,232,000.

**8. Target Number 8: Artillery Weapon with SFM Submunition as an Anti-Tank Weapon**

The target is a single tank positioned in the center of the target area. This is an attempt to test the SFM submunition when delivered to a target by means of an artillery carrier and used as a pinpoint accurate anti-tank weapon. The question is, can the weapon replace the anti-tank missile?

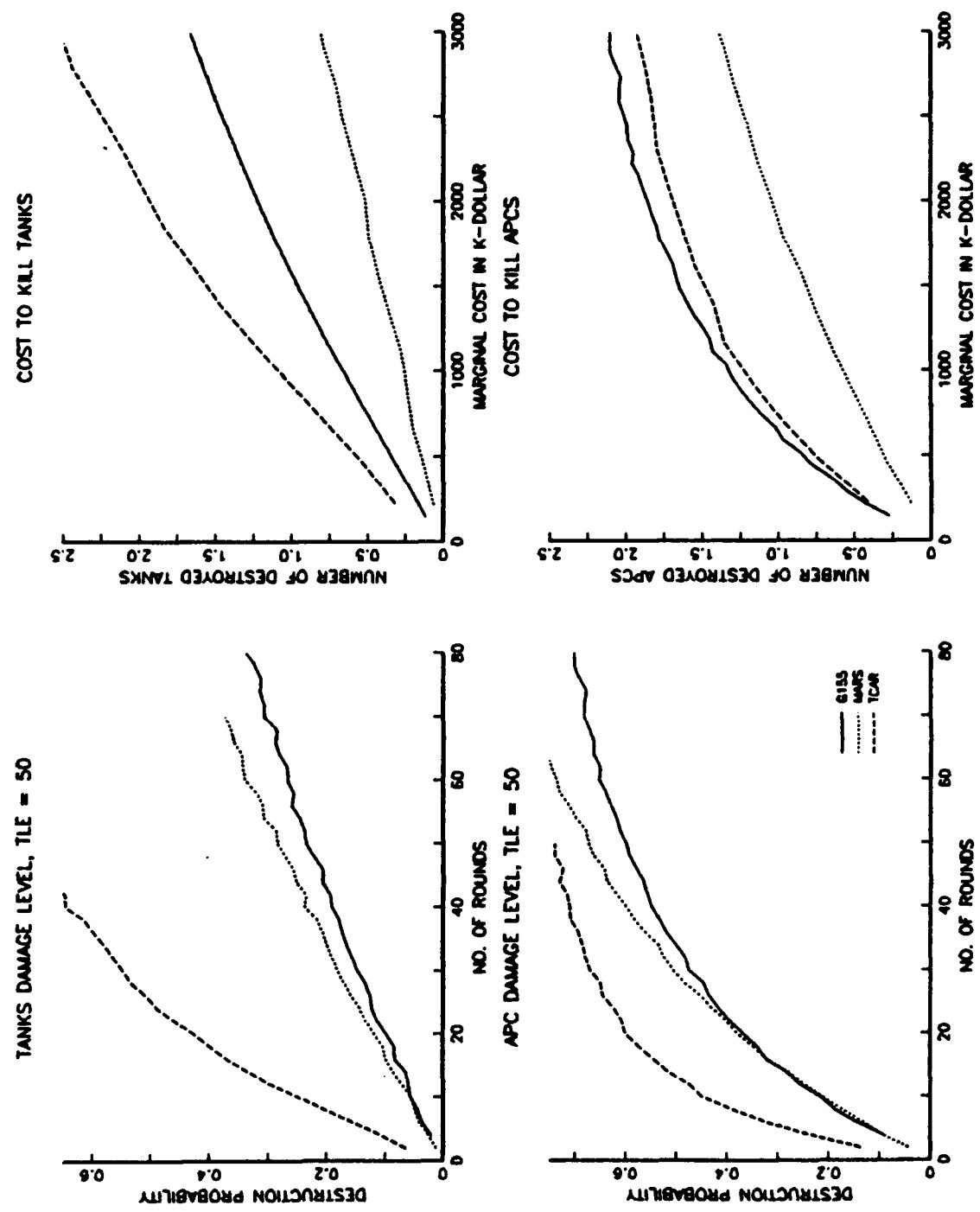


Figure 27. Target No. 7, SFM Warhead

Looking at the left graphs of Figure 28, we can conclude that, of the three systems we are considering, the TCAR is the only feasible system. It can achieve a 50 percent kill probability with 9 to 12 rockets with TLE of 25 to 50, respectively. However, the costs to achieve a 50 percent kill probability are between \$1,000,000 and \$1,300,000. Figure 29 shows the marginal cost of TCAR for TLE 25 and 50 m, in larger scale.

The simple answer to our question is, definitely, the SFM cannot replace anti-tank missiles because it more expensive and less rapid.

It must be understood that when a target contains many objects, the stochastic process is in play. That is, in a densely populated target area, if an artillery weapon misses object *a*, it is probable that it will instead hit object *b*, thereby accomplishing its mission (the probability rising with the object/density of the target).

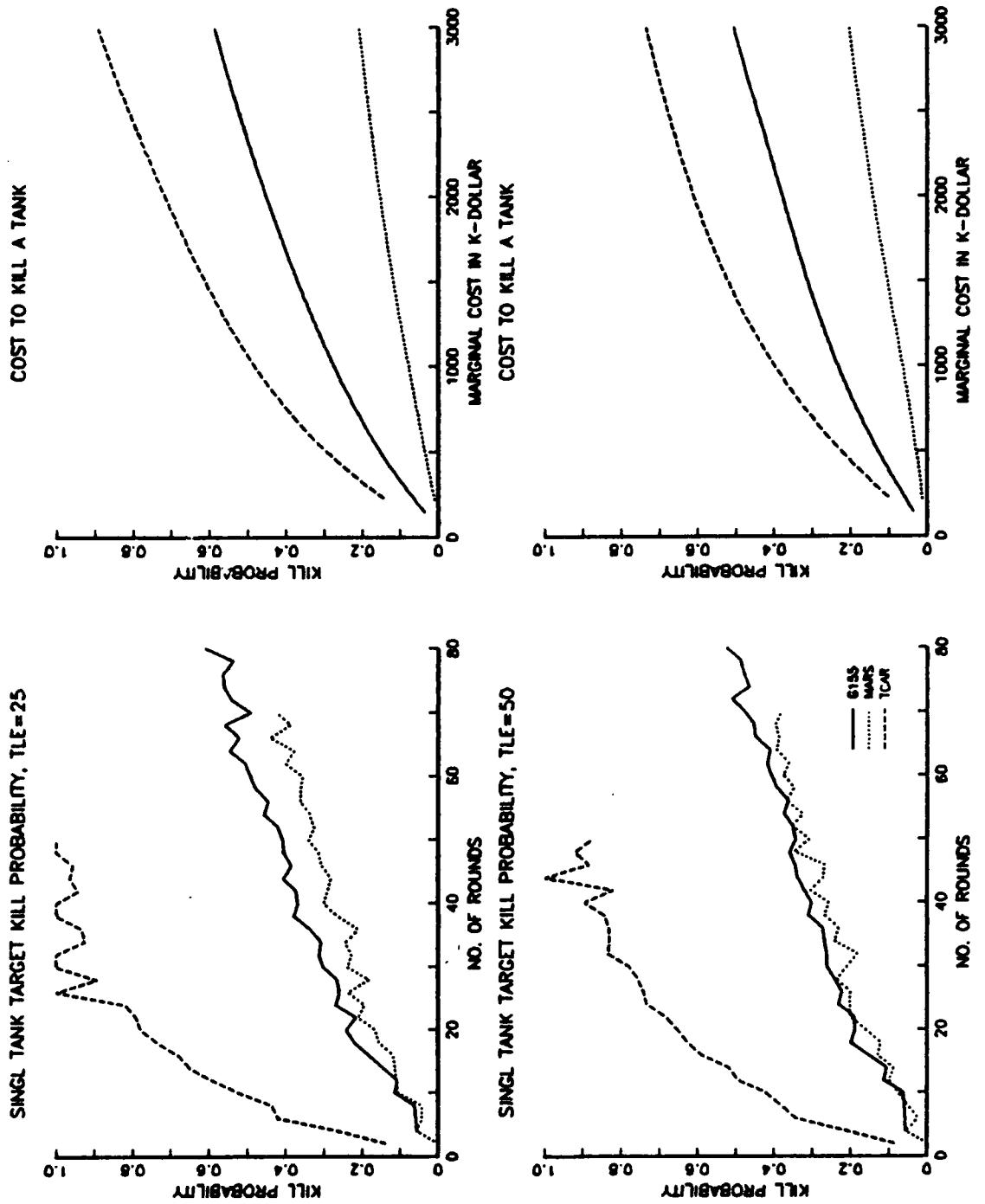


Figure 28. Target No. 8, SFM as an Anti-Tank Weapon

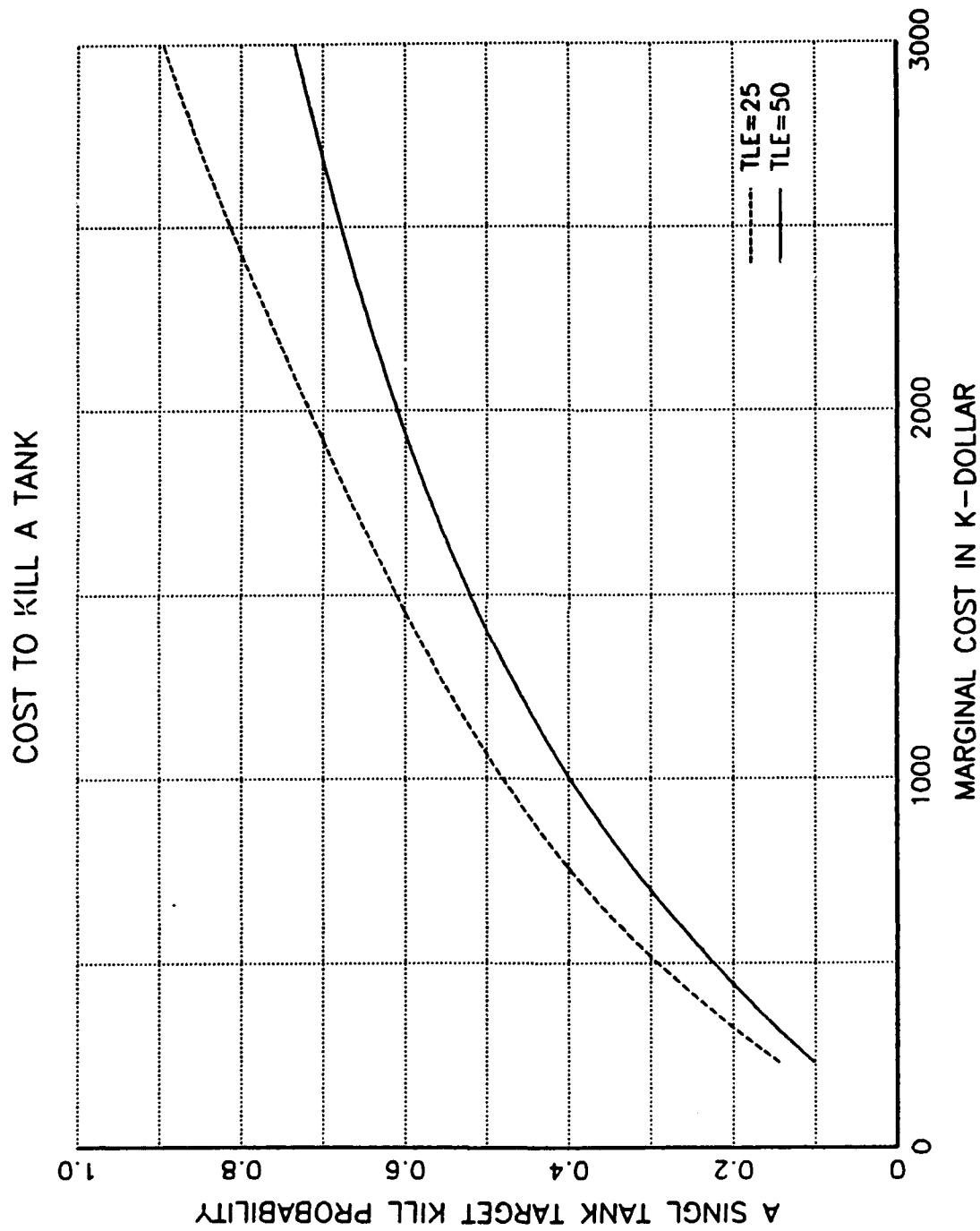


Figure 29. Target No. 8, TCAR with SFRM Warhead as an Anti-Tank Weapon

## **IV. CONCLUSIONS AND RECOMMENDATIONS**

The TCAR, as a version of a modern artillery rocket system, has all the artillery rocket system's advantages. However, by enhancing accuracy, a breakthrough in artillery concepts has been created. It is no longer a purely statistical weapon— it both is accurate and has massive kill capabilities that did not exist before.

### **A. EFFECTIVENESS AND MARGINAL COST**

With a cluster bomblet warhead:

- TCAR is capable of performing the highest rate of kill, far above the others, at a relatively affordable cost as compared to tube artillery.
- Tube artillery is the most cost-effective among the three systems. The TCAR is a close second, and MARS is the least cost-effective (far below).
- A battery of 155 mm howitzer guns will accomplish all missions better than a free-flight rocket system.

With an SFM warhead:

- The TCAR is the only system suitable for this kind of submunition. One must consider the difficulties of accommodating "smart" submunitions into projectiles. The severe launching shocks can damage the submunition and moderate performances (rate of kill/range) cause the G155 to be unsuitable for carrying "smart" submunitions. The end results are not worth the technological difficulties required to develop this type of weapon. Furthermore, the MARS capabilities are poor. In this regard, MARS carrying SFM is entirely infeasible.

### **B. ACCURACY**

Since the TCAR's accuracy does not depend on the range (to a limit), it has a longer maximum range than any other known artillery weapon. It

can hit targets located deep in an opponent's territory or engage a wider frontier section.

### C. RECOMMENDATIONS

Based on the analysis of this thesis, the author recommends that IMI Ltd. enter into full-scale development of the TCAR. The system is unique, so it has a high likelihood of being acquired.

This thesis provides a set of programs which can be used to evaluate damage assessment on more sets of targets with a variety of artillery system versions and updated real data. The tools developed here can be used to generate input data for some well-known and frequently used combat analysis programs.

The analysis shows a high sensitivity of results to TLE. When it becomes large, the effectiveness decreased very rapidly. It must be emphasized that all the impressive qualities of the TCAR represented in this thesis depend on the availability of a real-time, accurate intelligence system— one that provides the firing unit with information about enemy locations and one that observes the target continuously, giving reports in real time about the target's condition and the firing results. Without high-quality and rapid intelligence, the potential accuracy and lethality of the TCAR is wasted. To accomplish this, it would be necessary to integrate into the firing unit some type of a Remotely Piloted Vehicle (RPV) to be launched by, controlled by, and report directly to the firing unit.

## APPENDIX A

### NUMERICAL INTEGRATION OF THE PROBABILITY DENSITY FUNCTION OVER AN HOMOGENEOUS TARGET AREA— PROGRAM CODE

#### PROGRAM MAIN

```
C -----
C Assessment of damage level an homogeneous target subjected to
C Artillery fire of cluster bomblet projectiles or artillery
C rockets.
C The program prints, as output, the probability of a target
C (area) element to be destroyed by a salvo of n rockets.
C -----
C INDICES: Y - RANG, X - CROSS RANGE, T - TARGET, B - BIAS
C P - PRECISION
C -----
C PK1-The probability to kill a target element by a single round
C PKN-The probability to kill a target element by a salvo of N
C round
C XT, YT - Target coordinates
C XB, YB - Salvo bias coordinates
C AX, AY - Halves of rectangle target dimensions
C DXT, DYT - Area elements of the target
C DXB, DYB - Area elements of the bias coordinates set
C MAE - Mean area of effectiveness.
C NDXT, NDYT - Target number of segments
C NDXB, NDYB - Bias coordinates number of segments
C SIGMXP, SIGMYP - Precision, standard deviation of the rounds
C SIGMXB, SIGMYB - Accuracy, standard deviation of the salvo
C bias.
C N - Number of rounds in the salvo
C -----
C$INCLUDE: 'SYSTEM.DEF'
C$INCLUDE: 'TARGET.DEF'
C @@
INCLUDE 'SYSTEM DEF'
INCLUDE 'TARGET DEF'
C OPEN ( UNIT=1, FILE='SYSTEM.DTA', STATUS='OLD')
C OPEN ( UNIT=2, FILE='TARGET.DTA', STATUS='OLD')
C OPEN ( UNIT=3, FILE='TARGET.OUT', STATUS='OLD')
C @@
OPEN ( UNIT=1, FILE='/SYSTEM DATA', STATUS='OLD')
OPEN ( UNIT=2, FILE='/TARGET DATA', STATUS='OLD')
C
READ (1 , *) N, SIGMXP, SIGMYP, SIGMXB, SIGMYB, MAE
```

```

READ (2 , *) AX, AY, NDXT, NDYT, NDXB, NDYB
CALL SUBTARGET
STOP
END

C -----
      SUBROUTINE SUBTARGET
C

C -----
      REAL DP, DB, DXT, DYT, DXB, DYB, EAT, CDF, XB, YB, XT, YT
      REAL PX1, PKN, G(30,30), GA(30,30), F(30,30), PKTN(10,10)
      INTEGER I, J, K, L
C$INCLUDE: 'SYSTEM.DEF'
C$INCLUDE: 'TARGET.DEF'
C @@
      INCLUDE 'SYSTEM DEF'
      INCLUDE 'TARGET DEF'
      OPEN ( UNIT=3, FILE='TARGET OUT', STATUS='OLD')
C
      DP = 2*3.14159*SIGMXP*SIGMYP
      DB = 2*3.14159*SIGMXB*SIGMYB
      DXT = 2*AX / NDXT
      DYT = 2*AY / NDYT
      DXB = 3*SIGMXB / NDXB
      DYB = 3*SIGMYB / NDYB
C
      EAT = 0.
      CDF = 0.
C
      DO 100 I=1,NDXB
      DO 200 J=1,NDYB
         GA(I,J) = 0.
         XB = DXB/2. +(I-1)*DXB
         YB = DYB/2. +(J-1)*DYB
         DO 300 K=1, NDXT
            DO 400 L=1, NDYT
               XT = DXT/2. +(K-1)*DXT - AX
               YT = DYT/2. +(L-1)*DYT - AY
               PX1=(MAE/DP)*EXP(((XB-XT)/SIGMXP)**2
               & +((YB-YT)/SIGMYP)**2)/(-2.))
               PKTN(K,L) = 1-(1-PX1)**N
               GA(I,J) = GA(I,J) + PKTN(K,L)
400      CONTINUE
300      CONTINUE
         G(I,J) = GA(I,J)*DXT*DYT
         F(I,J) = (1./DB)*DXB*Dyb*EXP(((XB/SIGMXB)**2
         & +(YB/SIGMYB)**2)/(-2.))
         EAT = EAT + G(I,J)*F(I,J)
         CDF = CDF + F(I,J)
200      CONTINUE
100      CONTINUE

```

```

PKN = EAT / (AX*AY)
WRITE (3,10) PKN, EAT, 4*CDF, N ,MAE, AX, AY
WRITE (3,20) SIGMXP, SIGMYP, SIGMXB, SIGMYB
WRITE (3,30) NDXT, NDYT, NDXB, NDYB
WRITE (*,10) PKN, EAT, 4*CDF, N ,MAE, AX, AY
WRITE (*,20) SIGMXP, SIGMYP, SIGMXB, SIGMYB
WRITE (*,30) NDXT, NDYT, NDXB, NDYB
10  FORMAT (' DESTRUCTION PROBABILITY= ',F6.4 ,
& /' DESTROYED AREA (SQM)=',F8.0 ,/, ' PDF INTEGRAL=',F6.4 ,
& /' NO. OF ROUNDS=',I4 ,/, ' MEAN AREA OF EFFECTIVENESS',
& ' (SQM)=', F8.1 , /' TARGET HALF WIDTH (M)=',F7.2 ,
& /' TARGET HALF LENGTH (M)=',F7.2 )
20  FORMAT(' PRECISION CR STANDARD DEVIATION (M)=',F5.1 ,
& /' PRECISION RANGE STANDARD DEVIATION (M)=',F5.1 ,
& /' BIAS RANGE STANDARD DEVIATION (M)=',F5.1 ,
& /' BIAS CROS RANGE STANDARD DEVIATION (M)=',F5.1 )
30  FORMAT ( ' NO. OF SIGMENTS ON TARGET ',F4.0,'X',F4.0,/
& ' NO. OF SIGMENTS ON THE OPEN AREA ',F4.0,'X',F4.0 /)
      RETURN
      END

```

C

C -----

#### INCLUDE FILES

SYSTEM DEF

```

      REAL SIGMXP, SIGMYP, SIGMXB, SIGMYB, MAE
      INTEGER N
      COMMON/SYSTEM/N, SIGMXP, SIGMYP, SIGMXB, SIGMYB, MAE

```

TARGET DEF

```

      REAL AX, AY, NDXB, NDYB, NDXT, NDYT
      COMMON/TARGETDEF/ AX, AY, NDXB, NDYB, NDXT, NDYT
-----
```

## APPENDIX B

### TARGET DAMAGE ASSESSMENT, SIMULATION PROGRAMS CODE

```
PROGRAM MAIN300
C -----
C SIMULATION OF TARGET DAMAGE ASSESSMENT, CLUSTER BOMBLET WAREAHEADS
C -----
C THE PROGRAM READS SYSTEM AND TARGET DATA. IT CALLS FOR SALVOROND
C SUBROUTINE TO SIMULATE THE DAMAGE LEVEL CAUSED BY FIRING VARIABLE
C ROUNDS IN A SALVO.
C WHILE RECEIVING THE ONE SALVO RESULTS, THE PROGRAM CALLS FOR
C STATISTICS SUBROUTINE THAT CALCULATES CONSECUTIVELY, AVERAGE,
C STANDARD DEVIATIONS AND CONFIDENCE INTERVALS.
C THE PROGRAM STOPS WHEN THE CONFIDENCE INTERVAL FOR 95% CONFIDENCE
C IS REDUCED TO A FIXED RESOLUTION.
C SIMULATION OF 5 TARGET TYPES THAT ARE DEPLOYED IS THE SAME AREA
C CAN BE HANDLED SIMULTANEOUSLY.
C TYPICALLY ANY COMBINATION OF 5 CAN BE CHOSEN OUT OF THE FOLLOWING:
C TANK, APC, ARTILLERY GUN, SOFT VEHICLE, STANDING TROOPS, PRONE
C TROOPS, LAYING TROOPS AND CROUCHING (IN FOXHOLES ) TROOPS.
C
C AL(I)...LETHAL AREA OF A BOMBLET ON TARGET TYPE I
C AP...BOMBLET PATTERN ELLIPSOID, CROSS RANGE RADIUS
C BP...BOMBLET PATTERN ELLIPSOID, RANGE RADIUS
C NBOM...NUMBER OF BOMBLETS IN ONE ROUND.
C TD(I)...NUMBER OF TARGET TYPE I ELEMENTS THAT WHERE DESTROYED.
C RESOL...RESOLUTION
C NEXT(I,J)...LINK LIST MATRIX.
C
C -----
C$INCLUDE: 'CTARGET.DEF'
C$INCLUDE: 'CSEED.DEF'
C$INCLUDE: 'CSYSTEM.DEF'
C @@@
INCLUDE 'CTARGET DEF'
INCLUDE 'CSEED DEF'
INCLUDE 'CSYSTEM DEF'
C
INTEGER I, J, M, COUNT, TD(5), NBOM, NEXT(5,100)
INTEGER MINSALVO, MAXSALVO, INTERVAL
REAL TDAVG(5), TDSTD(5), RESOL(5), CONFINT, AL(5), DMGLEVEL(5,3)
REAL TLEX, TLEY
LOGICAL DONE
CHARACTER*8 TTYPE(5)
C @@@
OPEN ( 1, FILE='/TARGET6 DATA', STATUS='OLD')
OPEN ( 2, FILE='/WEAPON DATA', STATUS='OLD')
OPEN ( 3, FILE='/MAIN300 OUT', STATUS='OLD')
```

```

OPEN ( 4, FILE='/CSEED DATA', STATUS='OLD' )
OPEN ( 5, FILE='/MAIN300 LIST', STATUS='OLD' )

C
C
READ ( 2, * ) SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, NBOM
READ ( 2, * ) ( AL(I), I=1, 5 )
READ ( 2, * ) NPLAT, MINSALVO, MAXSALVO, INTERVAL, LTIME
READ ( 2, * ) NAPX, NAPY, DX, DY, TLEX, TLEY
READ ( 4, * ) ( SEED(I), I=1, 6 )

C
DATA RESOL / .1, .1, .1, .1, .6 /
C
SIGXB = SQRT(SIGXB**2 + TLEX**2)
SIGYB = SQRT(SIGYB**2 + TLEY**2)

C
DO 100 I=1, 5
  READ (1, *) N(I), TTYPE(I), ( DMGLEVEL(I,M), M = 1, 3 )
  DO 110 J=1, N(I)
    READ (1, *) X(I,J), Y(I,J)
    NEXT(I, J) = J + 1
110 CONTINUE
C
IF ( N(I) .GT. 0 ) NEXT(I, N(I)) = 0
PK1(I) = 1 - ( 1 - AL(I) / ( 3.14159*AP*BP ) )**NBOM
100 CONTINUE
C
WRITE (5, 40) SIGXB, SIGYB, NAPX, DX, TLEX, TLEY
C
DO 200 NSALVO = MINSALVO, MAXSALVO, INTERVAL
COUNT = 0
DO 201 I=1, 5
  TD(I) = 0
  TDAVG(I) = 0.0
201 CONTINUE
C
C
300 CONTINUE
PRINT*, 'FROM MAIN COUNT=', COUNT, 'AP=', AP, 'BP=', BP
DONE = .TRUE.
CALL SALVOROUND ( NEXT, NSALVO, TD )
DO 350 I = 1, 5
  IF ( N(I) .GT. 0 ) THEN
    CALL STATISTICS ( COUNT, TD(I), TDAVG(I), TDSTD(I) )
    IF ( CONFINT(COUNT, TDSTD(I)).GT.RESOL(I) ) DONE = .FALSE.
    IF ( COUNT .LT. 3 ) DONE = .FALSE.
  ENDIF
350 CONTINUE
  COUNT = COUNT + 1
  IF ( .NOT. DONE ) GO TO 300
C
C
WRITE (3, *)
WRITE (3, *) ' SALVO=', NSALVO, ' REPEAT=', COUNT
WRITE (3, 10) ( TTYPE(I), TDAVG(I), I = 1, 5 )
WRITE (3, 20) ( TTYPE(I), TDAVG(I)/(N(I)+.001), I = 1, 5 )
WRITE (5, 30) NSALVO, ((TDAVG(I)/(N(I)+.001))*100, I = 1, 5)

```

```
200 CONTINUE
C      WRITE (*, *)  'PK1(I)= ',( PK1(I), I=1,5 ),' REPEAT=',COUNT
C
C
C
10  FORMAT (/,5(1X,A7,'=',F4.1) )
20  FORMAT ( 5(1X,A7,'=',F4.3) )
30  FORMAT ( 1X,I4,5(1X,F4.1) )
40  FORMAT (' SIGXB=',F7.2,' SIGYB=',F7.2,' NAPX=',I2,' DX=',F6.1,
& ' TLEX=',F6.2, ' TLEY=',F6.2 )
      STOP
      END
```

---

```

SUBROUTINE SALVOROUND( NEXTMATRIX, NSALVO, SCORE )
C -----
C SIMULATION OF DAMAGE LEVEL WHEN FIRING A SALVO OF FIXED ROUNDS
C -----
C
C THE SUBROUTINE ACCEPTS THE TARGET ELEMENTS LINKED BY A LINK LIST
C MATRIX. SAMPLE A BIAS ERROR. SAMPLE PRECISION ERROR. SEARCH FOR
C A TARGET ELEMENT IN THE PATTERN ELLIPSOID. IF FOUND, IT IS
C ELIMINATED FROM THE LIST. COUNT NUMBER OF ELIMINATIONS.
C WHEN SALVO PREDETERMINED ROUNDS WHERE COMPLETED, RETURNS.
C
C -----
C
CINCLUDE: 'CTARGET.DEF'
CINCLUDE: 'CSEED.DEF'
CINCLUDE: 'SYS100.DEF'
C @@@
INCLUDE 'CSYSTEM DEF'
INCLUDE 'CTARGET DEF'
INCLUDE 'CSEED DEF'
C @@@
INTEGER ROUND, I, J, SCORE(5), FIRST(5), PNT, NEXT(5,100)
INTEGER NEXTMATRIX(5, 100), NSALVO
REAL TIME, XB, XH, XP, YB, YH, YP, RAN, SPLITX, SPLITY
LOGICAL FST
C
CALL RANNUM( 2, SEED(1), 0.0, SIGXB, 0, XB )
CALL RANNUM( 2, SEED(2), 0.0, SIGYB, 0, YB )
C
ROUND = 0
TIME = 0.0
DO 101 I = 1, 5
  FIRST(I) = 1
  SCORE(I) = 0
  DO 102 J = 1, N(I)
    NEXT(I, J) = NEXTMATRIX(I, J)
102 CONTINUE
101 CONTINUE
C
100 CONTINUE
ROUND = ROUND + 1
CALL RANNUM( 2, SEED(3), 0.0, SIGXP, 0, XP )
CALL RANNUM( 2, SEED(4), 0.0, SIGYP, 0, YP )
XH = XB + XP
YH = YB + YP
IF ( NAPX .GT. 1 ) XH = XH + SPLITX(ROUND, NSALVO, NAPX, DX)
IF ( NAPY .GT. 1 ) YH = YH + SPLITY(ROUND, NSALVO, NAPY, DY)
DO 300 I = 1, 5
  IF ( N(I) .GT. 0 ) THEN
    150 CONTINUE
    IF ( FIRST(I) .GT. 0 ) THEN
      FST = .FALSE.
      J = FIRST(I)
      WRITE(3,*) 'FROM SALVO 1 ROUND=',ROUND, ' J=',J
      IF (((((XH-X(I,J))/AP)**2+((YH-Y(I,J))/BP)**2).LT.1.)THEN
        CALL RANNUM( 1, SEED(5), 0.0, 1.0, 0, RAN )

```

```

        IF ( RAN .LT. PK1(I) ) THEN
            FIRST(I) = NEXT(I,J)
            SCORE(I) = SCORE(I) + 1
            FST = .TRUE.
        ENDIF
    ENDIF
    IF ( FST ) GO TO 150
    PNT = FIRST(I)

C
C 200
C
200    IF ( NEXT(I, J) .GT. 0 ) THEN
        J = NEXT(I,J)
        IF(((XH-X(I,J))/AP)**2+((YH-Y(I,J))/BP)**2).LT.1.)THEN
            CALL RANNUM( 1, SEED(5), 0.0, 1.0, 0, RAN )
            IF ( RAN .LT. PK1(I) ) THEN
                NEXT(I,PNT) = NEXT(I,J)
                SCORE(I) = SCORE(I) + 1
            ELSE
                PNT = J
            ENDIF
        ELSE
            PNT = J
        ENDIF
        GO TO 200
    ENDIF
    ENDIF
    ENDIF
300    CONTINUE
C
C
IF ( ROUND .LT. NSALVO ) GO TO 100
C
RETURN
END
-----
```

#### INCLUDE FILES

```

CSYSTEM DEF
C
INTEGER NAPX, NAPY
REAL SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, PK1(5), DX, DY
COMMON /SYSTEM/ SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, PK1,
& NAPX, NAPY, DX, DY
C
C PK1(I)...PROBABILITY TO KILL A TARGET TYPE I IN THE PATTERN OF ONE
C WARHEAD
C RATE...RATE OF FIRE OF ONE PLATFORM
C NAPX, NAPY... NUMBER OF AIMPOINTS ON THE TARGET
C DX, DY ... MAX. DISTANCE OF AIMPOINT DEVIATION FROM THE TARGET CENTER
C
-----
```

```

CTARGET DEF
C
```

```
INTEGER N(5), NPAT
```

REAL X(5,100), Y(5,100), LTIME  
COMMON/TARGET/ X, Y, N, NPLAT, LTIME

C

-----  
CSEED DEF

C

INTEGER SEED(8)  
COMMON/SEED SET/ SEED

C

PROGRAM MAINTIME

```
C -----
C SIMULATION OF TARGET DAMAGE ASSESSMENT, CLUSTER BOMBLET WAREAHEADS
C IN THIS SIMULATION LETHAL AREA DECREASES AS A FUNCTION OF SALVO
C TIME DURATION.
C -----
C
C THE PROGRAM READS SYSTEM AND TARGET DATA. IT CALLS FOR SALVOROND
C SUBROUTINE TO SIMULATE THE DAMAGE LEVEL CAUSED BY FIRING VARIABLE
C ROUNDS IN A SALVO.
C WHILE RECEIVING THE ONE SALVO RESULTS, THE PROGRAM CALLS FOR
C STATISTICS SUBROUTINE THAT CALCULATE CONSECUTIVELY, AVERAGE,
C STANDARD DEVIATIONS AND CONFIDENCE INTERVALS.
C THE PROGRAM STOPS WHEN THE CONFIDENCE INTERVAL FOR 95% CONFIDENCE
C IS REDUCED TO A FIXED RESOLUTION.
C SIMULATION OF 5 TARGET TYPES THAT ARE DEPLOYED IS THE SAME AREA
C CAN BE HANDLED SIMULTANEOUSLY.
C TYPICALLY ANY COMBINATION OF 5 CAN BE CHOSEN OUT OF THE FOLLOWING:
C TANK, APC, ARTILLERY GUN, SOFT VEHICLE, STANDING TROOPS, PRONE
C TROOPS, LAYING TROOPS AND CROUCHING (IN FOXHOLES ) TROOPS.
C
C AL(I)...LETHAL AREA OF A BOMBLET ON TARGET TYPE I
C AP...BOMBLET PATTERN ELLIPSOID, CROSS RANGE RADIUS
C BP...BOMBLET PATTERN ELLIPSOID, RANGE RADIUS
C NBOM...NUMBER OF BOMBLETS IN ONE ROUND.
C TD(I)...NUMBER OF TARGET TYPE I ELEMENTS THAT WHERE DESTROYED.
C RESOL...RESOLUTION
C NEXT(I,J)...LINK LIST MATRIX.
C
C -----
C$INCLUDE: 'CTARGET.DEF'
C$INCLUDE: 'CSEED.DEF'
C$INCLUDE: 'C400SYST.DEF'
C @@@
INCLUDE 'CTARGET DEF'
INCLUDE 'CSEED DEF'
INCLUDE 'C400SYST DEF'
C
INTEGER I, J, M, COUNT, TD(5), NEXT(5,100)
INTEGER MINSALVO, MAXSALVO, INTERVAL
REAL TDAVG(5), TDSTD(5), RESOL(5), CONFINT
LOGICAL DONE
CHARACTER*8 TTYPE(5)
C
OPEN ( 1, FILE='TARGET.DTA', STATUS='OLD')
OPEN ( 2, FILE='SYSTEM.DTA', STATUS='OLD')
OPEN ( 3, FILE='SYSTEM.OUT', STATUS='OLD')
OPEN ( 4, FILE='SEED.DTA', STATUS='OLD' )
C @@@
OPEN ( 1, FILE='/TARGET1 DATA', STATUS='OLD')
OPEN ( 2, FILE='/WEAPON DATA', STATUS='OLD')
C OPEN ( 2, FILE='/CSYSTEM DATA', STATUS='OLD')
OPEN ( 3, FILE='/TIME OUT', STATUS='OLD')
OPEN ( 4, FILE='/CSEED DATA', STATUS='OLD' )
OPEN ( 5, FILE='/TIMELIST OUT', STATUS='OLD')
C
```

```

READ ( 2, *) SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, NBOM
READ ( 2, *) ( AL(I), I=1, 5 ) ,AL0
READ ( 2, *) NPLAT, MINSALVO, MAXSALVO, INTERVAL, (GAMMA(I),I=1,5)
READ ( 4, *) ( SEED(I), I=1,6)
C
DATA RESOL / .8, .8, .8, .8, .8 /
C
DO 100 I=1, 5
  READ (1, *) N(I) , TTYPE(I)
  DO 110 J=1, N(I)
    READ (1, *) X(I,J), Y(I,J)
    NEXT(I, J) = J + 1
110      CONTINUE
C
IF ( N(I) .GT. 0 ) NEXT(I, N(I)) = 0
100 CONTINUE
C
DO 200 NSALVO = MINSALVO, MAXSALVO, INTERVAL
  COUNT = 0
  DO 201 I=1, 5
    TD(I) = 0
    TDAVG(I) = 0.0
201      CONTINUE
C
C
300      CONTINUE
C
PRINT*, 'FROM MAIN COUNT=',COUNT, 'AP=',AP, 'BP=',BP
DONE = .TRUE.
CALL SALVOTIME( NEXT, NSALVO, TD )
DO 350 I = 1, 5
  IF ( N(I) .GT. 0 ) THEN
    CALL STATISTICS ( COUNT, TD(I), TDAVG(I), TDSTD(I) )
    IF (CONFINT(COUNT,TDSTD(I)).GT.RESOL(I))DONE = .FALSE.
    IF ( COUNT .LT. 3 ) DONE = .FALSE.
  ENDIF
350      CONTINUE
  COUNT = COUNT + 1
  IF ( .NOT. DONE ) GO TO 300
C
C
WRITE (3, *)
WRITE (3, *) ' SALVO=',NSALVO , ' REPEAT=',COUNT
WRITE (3,10) ( TTYPE(I), TDAVG(I), I = 1, 5 )
WRITE (3,20) ( TTYPE(I), TDAVG(I)/(N(I)+.001), I = 1, 5)
WRITE (5,30)  NSALVO,((TDAVG(I)/(N(I)+.001))*100, I = 1, 5)
C
200 CONTINUE
C
C
10 FORMAT (/,5(1X,A7,'=',F4.1) )
20 FORMAT ( 5(1X,A7,'=',F4.3) )
30 FORMAT ( 1X,I4,5(1X,F4.1) )
STOP
END

```

```

SUBROUTINE SALVOTIME( NEXTMATRIX, NSALVO, SCORE )

C -----
C SIMULATION OF DAMAGE LEVEL WHEN FIRING A SALVO OF FIXED ROUNDS
C IN THIS SIMULATION LETHAL AREA IS DECREASED AS FUNCTION OF THE
C SALVO TIME DURATION
C -----
C
C THE SUBROUTINE ACCEPTS THE TARGET ELEMENTS LINKED BY A LINK LIST
C MATRIX. SAMPLE A BIAS ERROR. SAMPLE PRECISION ERROR. SEARCH FOR
C A TARGET ELEMENT IN THE PATTERN ELLIPSOID. IF FOUND, IT IS
C ELIMINATED FROM THE LIST. COUNT NUMBER OF ELIMINATIONS.
C WHEN SALVO PREDETERMINED ROUNDS WHERE COMPLETED, RETURNS.
C
C -----
C
CINCLUDE: 'CTARGET.DEF'
CINCLUDE: 'CSEED.DEF'
CINCLUDE: 'C400SYST.DEF'
C @@@
INCLUDE 'C400SYST DEF'
INCLUDE 'CTARGET DEF'
INCLUDE 'CSEED DEF'
C @@@
      INTEGER ROUND, I, J, SCORE(5), FIRST(5), PNT, NEXT(5,100)
      INTEGER NEXTMATRIX(5, 100), NSALVO
      REAL TIME, XB, XH, XP, YB, YH, YP, RAN, PK1, ALT
      LOGICAL FST
C
      CALL RANNUM( 2, SEED(1), 0.0, SIGXB, 0, XB )
      CALL RANNUM( 2, SEED(2), 0.0, SIGYB, 0, YB )
C
      ROUND = 0
      TIME = 0.0
      DO 101 I = 1, 5
         FIRST(I) = 1
         SCORE(I) = 0
         DO 102 J = 1, N(I)
            NEXT(I, J) = NEXTMATRIX(I, J)
102      CONTINUE
101      CONTINUE
C
      100 CONTINUE
      ROUND = ROUND + 1
      TIME = TIME + ROUND / NPLAT / RATE
      CALL RANNUM( 2, SEED(3), 0.0, SIGXP, 0, XP )
      CALL RANNUM( 2, SEED(4), 0.0, SIGYP, 0, YP )
      XH = XB + XP
      YH = YB + YP
      DO 300 I = 1, 5
         IF ( N(I) .GT. 0 ) THEN
            ALT = AL0+(AL(I)-AL0)*EXP(-GAMMA(I)*TIME)
            PK1 = 1. - ( 1. - ALT / ( 3.14159*AP*BP ) )**NBOM
150      CONTINUE
         IF ( FIRST(I) .GT. 0 ) THEN
            FST = .FALSE.

```

```

J = FIRST(I)
C      WRITE(3,*) 'FROM SALVO 1 ROUND=',ROUND,' J=',J
      IF(((XH-X(I,J))/AP)**2+((YH-Y(I,J))/BP)**2).LT.1.)THEN
          CALL RANNUM( 1, SEED(5), 0.0, 1.0, 0, RAN )
          IF ( RAN .LT. PK1 ) THEN
              FIRST(I) = NEXT(I,J)
              SCORE(I) = SCORE(I) + 1
              FST = .TRUE.
          ENDIF
      ENDIF
      IF ( FST ) GO TO 150
      PNT = FIRST(I)

C 200
C
C 200      IF ( NEXT(I, J) .GT. 0 ) THEN
      J = NEXT(I,J)
      IF(((XH-X(I,J))/AP)**2+((YH-Y(I,J))/BP)**2).LT.1.)THEN
          CALL RANNUM( 1, SEED(5), 0.0, 1.0, 0, RAN )
          IF ( RAN .LT. PK1 ) THEN
              NEXT(I,PNT) = NEXT(I,J)
              SCORE(I) = SCORE(I) + 1
          ELSE
              PNT = J
          ENDIF
      ELSE
          PNT = J
      ENDIF
      GO TO 200
      ENDIF
      ENDIF
      ENDIF
      ENDIF
      ENDIF
      CONTINUE
C
C 300      IF ( ROUND .LT. NSALVO ) GO TO 100
C
C      RETURN
C

```

---

INCLUDE\_FILE

```

C400SYST DEF
C
C      REAL SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, AL(5), GAMMA(5)
      REAL ALO
      INTEGER NBOM
      COMMON /SYSTEM/ SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, F,
      & NBOM, GAMMA, ALO
C
C      RATE...RATE OF FIRE OF ONE PLATFORM
C
CTARGET DEF
      INTEGER N(5), NPLAT

```

```
REAL X(5,100), Y(5,100), LTIME  
COMMON/TARGET/ X, Y, N, NPLAT, LTIME  
C  
CSEED DEF  
C  
INTEGER SEED(8)  
COMMON/SEED SET/ SEED  
C
```

```

PROGRAM SMARTMAIN
C -----
C SIMULATION OF TARGET DAMAGE ASSESSMENT, SMART SUBMUNITION WAREAHEADS
C -----
C
C THE PROGRAM READS SYSTEM AND TARGET DATA. IT CALLS FOR SMARTSALVO
C SUBROUTINE TO SIMULATE THE DAMAGE LEVEL CAUSED BY FIRING VARIABLE
C ROUNDS IN A SALVO.
C WHILE RECEIVING THE ONE SALVO RESULTS, THE PROGRAM CALLS FOR
C STATISTICS SUBROUTINE THAT CALCULATE CONSECUTIVELY, AVERAGE,
C STANDARD DEVIATIONS AND CONFIDENCE INTERVALS.
C THE PROGRAM STOPS WHEN THE CONFIDENCE INTERVAL FOR 95% CONFIDENCE
C IS REDUCED TO A FIXED RESOLUTION.
C SIMULATION OF 5 TARGET TYPES THAT ARE DEPLOYED IS THE SAME AREA
C CAN BE HANDLED SIMULTANEOUSLY.
C TYPICALLY ANY COMBINATION OF 5 CAN BE CHOSEN LIKE THE FOLLOWING:
C TANK, APC, SELF-PROPELLED ARTILLERY GUN, SOFT VEHICLE.
C
C TD(I)...NUMBER OF TARGET TYPE I ELEMENTS THAT WHERE DESTROYED.
C RESOL...RESOLUTION
C
C -----
C$INCLUDE: 'CTARGET.DEF'
C$INCLUDE: 'CSEED.DEF'
C$INCLUDE: 'SMARTSYS.DEF'
C$INCLUDE: 'SEARCH.DEF'
C @@@
      INCLUDE 'CTARGET DEF'
      INCLUDE 'CSEED DEF'
      INCLUDE 'SMARTSS DEF'
      INCLUDE 'SEARCH DEF'

C
      INTEGER I, J, COUNT, TD(5)
      INTEGER MINSALVO, MAXSALVO, INTERVAL, NSALVO
      REAL TDAVG(5), TDSTD(5), RESOL(5), CONFINT, TLEX, TLEY
      LOGICAL DONE
      CHARACTER*8 TTYPE(5)

C
      OPEN ( 1, FILE='SMARTTAR.DTA', STATUS='OLD')
      OPEN ( 2, FILE='SMARTSYS.DTA', STATUS='NEW')
      OPEN ( 3, FILE='SYSTEM.OUT', STATUS='OLD')
      OPEN ( 4, FILE='SEED.DTA', STATUS='OLD' )

C @@@
      OPEN ( 1, FILE='/TARGET7A DATA', STATUS='OLD')
      OPEN ( 2, FILE='/SMARTSS DATA', STATUS='OLD')
      OPEN ( 3, FILE='/CSYSTEM OUT', STATUS='OLD')
      OPEN ( 4, FILE='/CSEED DATA', STATUS='OLD' )
      OPEN ( 5, FILE='/SMARTMN LIST', STATUS='OLD' )

C
      READ ( 2, *) SIGXP,SIGYP,SIGXB,SIGYB,SIGMAR,DIST,RSEARCH,R1,R2
      READ ( 2, *) (PRH1(I), I=1, 5), (PRH2(I), I=1,5), (PRH3(I), I=1,5)
      READ ( 2, *) (PRK1(I), I=1, 5), (PRK2(I), I=1,5), (PRK3(I), I=1,5)
      READ ( 2, *) NPLAT, MINSALVO, MAXSALVO, INTERVAL, NSUB
      READ ( 2, *) NAPX, NAPY, DX, DY, TLEX, TLEY
      READ ( 4, *) ( SEED(I), I=1,8)

```

```

      DATA RESOL / .1, .1, .1, .1, .01 /
C
      SIGXB = SQRT(SIGXB**2 + TLEX**2)
      SIGYB = SQRT(SIGYB**2 + TLEY**2)
C
      DO 100 I=1, 5
         READ (1, *) N(I) , TTYPE(I)
         DO 100 J=1, N(I)
            READ (1, *) X(I,J), Y(I,J)
100   CONTINUE
C
      WRITE (5, 40) SIGXB, SIGYB, NAPX, DX, TLEX, TLEY
C
      DO 200 NSALVO = MINSALVO, MAXSALVO, INTERVAL
         COUNT = 0
         DO 201 I=1, 5
            TD(I) = 0
            TDAVG(I) = 0.0
201   CONTINUE
C
C
      300  CONTINUE
C
      PRINT*, 'FROM MAIN COUNT=' , COUNT, 'AP=' , AP, 'BP=' , BP
      DONE = .TRUE.
      CALL SMARTSALVO ( NSALVO, TD )
      DO 350 I = 1, 5
         IF ( N(I) .GT. 0 ) THEN
            CALL STATISTICS ( COUNT, TD(I), TDAVG(I), TDSTD(I) )
            IF (CONFINT(COUNT,TDSTD(I)).GT.RESOL(I))DONE = .FALSE.
            IF ( COUNT .LT. 10) DONE = .FALSE.
         ENDIF
350   CONTINUE
         COUNT = COUNT + 1
         IF ( .NOT. DONE ) GO TO 300
C
C
      WRITE (3, *)
      WRITE (3, *) ' SALVO=' , NSALVO , ' REPEAT=' , COUNT
      WRITE (3, 10) ( TTYPE(I), TDAVG(I), I = 1, 5 )
      WRITE (3, 20) ( TTYPE(I), TDAVG(I)/(N(I)+.001), I = 1, 5 )
      WRITE (5, 30) NSALVO, ((TDAVG(I)/(N(I)+.001))*100, I = 1, 5)
200   CONTINUE
C
C
      10 FORMAT (/,5(1X,A7,'-',F4.1) )
      20 FORMAT ( 5(1X,A7,'-',F4.3) )
      30 FORMAT ( 1X,I4,5(1X,F4.1) )
      40 FORMAT (' SIGXB=' , F7.2, ' SIGYB=' , F7.2, ' NAPX=' , I2, ' DX=' , F6.1,
& ' TLEX=' , F6.2, ' TLEY=' , F6.2 )
      STOP
      END

```

```

SUBROUTINE SMARTSALVO( NSALVO, SCORE )
C
C-----  

C THIS SUBROUTINE SIMULATES TARGET DAMAGE LEVEL AFTER FIRING A SALVO  

C OF SMART WARHEAD ROUNDS.  

C -----  

C  

C THE SUBROUTINE ACCEPTS THE TARGET ELEMENTS, LISTED IN X Y LOCATION  

C ARRAYS. SAMPLES A BIAS ERROR. SAMPLES PRECISION ERROR. SAMPLE  

C SUBMUNITION DISPERSION. SEARCHES FOR A TARGET ELEMENTS INSIDE THE  

C THE SUBMUNITION SEARCHING CIRCLE. IF FOUND, IT IS RECORDED IN A  

C DETECTED LIST. AMONG THE POTENTIALLY DETECTED TARGETS, ONE KILLED  

C TARGET, PER ONE SUBMUNITION IS CHOSEN, IN ORDER OF THE FARER FROM THE  

C SEARCHING CENTER, THE FIRST TO BE SAMPLED. COUNT NUMBER OF KILLED  

C TARGETS. WHEN SALVO PREDETERMINED ROUNDS IS COMPLETED, RETURNS.  

C
C -----
C
C$INCLUDE: 'CTARGET.DEF'
C$INCLUDE: 'CSEED.DEF'
C$INCLUDE: 'SMARTSS.DEF'
C @@@
INCLUDE 'CTARGET DEF'
INCLUDE 'CSEED DEF'
INCLUDE 'SMARTSS DEF'
C @@@
INTEGER ROUND, I, J, L, K, SCORE(5), II(500), JJ(500)
INTEGER NSALVO, SUB(500), ISUB, PNT, IPNT, ND
REAL XB, YB, XP, YP, THETA, RAN, XCS, YCS, RR(500), SPLITX
REAL XX(5,100), YY(5,100), RMAX, DISTR, RANGE, PH1, PK1, SPLITY
C
CALL RANNUM( 2, SEED(1), 0.0, SIGXB, 0, XB )
CALL RANNUM( 2, SEED(2), 0.0, SIGYB, 0, YB )
C
IF ( NAPX .GT. 1 ) XB = XB + SPLITX(ROUND, NSALVO, NAPX, DX)
IF ( NAPY .GT. 1 ) YB = YB + SPLITY(ROUND, NSALVO, NAPY, DY)
C
ROUND = 0
DO 101 I = 1, 5
  SCORE(I) = 0
  DO 102 J = 1, N(I)
    XX(I, J) = X(I, J)
    YY(I, J) = Y(I, J)
102   CONTINUE
101   CONTINUE
C
100 CONTINUE
C
PRINT*, 'I AM IN THE SALVO LOOP ,ROUND=',ROUND,(N(I),I=1,5)
ROUND = ROUND + 1
CALL RANNUM( 2, SEED(3), 0.0, SIGXP, 0, XP )
CALL RANNUM( 2, SEED(4), 0.0, SIGYP, 0, YP )
PNT = 1
C
DO 200 ISUB = 1, NSUB
  CALL RANNUM( 2, SEED(4), DIST, SIGMAR, 0, DISTR )
  CALL RANNUM( 1, SEED(5), 0.0, 6.28319, 0, THETA )

```

```

C
      XCS = XB + XP + DISTR*COS(THETA)
      YCS = YB + YP + DISTR*SIN(THETA)
C      PRINT*, 'XCS=',XCS,'YCS=',YCS
C
      DO 300 I = 1, 5
         IF ( N(I) .GT. 0 ) THEN
            DO 400 J = 1, N(I)
               RANGE = SQRT( (XCS-XX(I,J))**2+(YCS-YY(I,J))**2 )
               IF ( RANGE .LT. RSEARCH ) THEN
                  II(PNT) = I
                  JJ(PNT) = J
                  RR(PNT) = RANGE
                  SUB(PNT) = ISUB
                  PNT = PNT + 1
               ENDIF
300          CONTINUE
            ENDIF
200          CONTINUE
C
C
      700 CONTINUE
         RMAX = 0.0
         DO 500 L = 1, PNT - 1
            IF ( SUB(L) .GT. 0 ) THEN
               IF ( RR(L) .GT. RMAX ) THEN
                  RMAX = RR(L)
                  IPNT = L
               ENDIF
            ENDIF
500          CONTINUE
C
C @@@@@@@
C      WRITE(3, 555) ( II(LL),JJ(LL),RR(LL),SUB(LL) ,LL=1,PNT-1)
C 555      FORMAT (I4,I4,F6.2,I3)
C      WRITE(3,*) 'IPNT=',IPNT,'PNT=',PNT,'RMAX=',RMAX,'ROUND=',ROUND
C @@@@@@@
C
         IF ( RMAX .LT. 0.1 ) GO TO 800
C
         CALL RANNUM( 1, SEED(6), 0.0, 1.0, 0, RAN )
         IF ( RAN .LT. PH1(II(IPNT),RMAX) ) THEN
            ND = SUB(IPNT)
            DO 600 K = 1, (PNT - 1)
               IF ( SUB(K) .EQ. ND ) SUB(K) = 0
600          CONTINUE
C
         CALL RANNUM( 1, SEED(7), 0.0, 1.0, 0, RAN )
         IF ( RAN .LT. PK1(II(IPNT),RMAX) ) THEN
C .....IN CASE OF A KILLED TARGET CAN BE HIT AGAIN
C           IF(II(K).EQ.II(IPNT).AND.JJ(K).EQ.JJ(IPNT).AND.
C             & XX(II(K)) .EQ. 1000000 ) )
C .....MUST BE PUT AS NEGATIVE CONDITION
            SCORE(II(IPNT)) = SCORE(II(IPNT)) + 1
            XX(II(IPNT),JJ(IPNT)) = 1000000.

```

```

        DO 650 K = 1, (PNT - 1)
        IF (II(K).EQ.II(IPNT).AND.JJ(K).EQ.JJ(IPNT)) RR(K)--1.
650      CONTINUE
        ENDIF
        ENDIF
        RR(IPNT) = -1.
        GO TO 700
C
C     800  CONTINUE
C
C     IF ( ROUND .LT. NSALVO ) GO TO 100
C
C     PRINT*, (SCORE(I), I=1,5)
C     RETURN
C     END
C -----
C     REAL FUNCTION PH1(I, R)
C -----
C THIS FUNCTION DETERMINES THE HIT PROBABILITY GIVEN EXSISTANCE
C OF TAGET INSIDE THE SUBMUNITION SEARCHING CIRCLE.
C -----
C     INTEGER I
C     REAL R
C$INCLUDE: 'SEARCH.DEF'
INCLUDE 'SEARCH DEF'
IF ( R .LT. R1 ) THEN
    PH1 = PRH1(I)
ELSEIF ( R .LT. R2 ) THEN
    PH1= PRH2(I)
ELSE
    PH1 = PRH3(I)
ENDIF
RETURN
END
C -----
C     REAL FUNCTION PK1(I, R)
C -----
C THIS FUNCTION DETERMINES THE KILL PROBABILITY GIVEN EXSISTANCE
C OF TAGET INSIDE THE SUBMUNITION SEARCHING CIRCLE.
C -----
C     INTEGER I
C     REAL R
C$INCLUDE: 'SEARCH.DEF'
INCLUDE 'SEARCH DEF'
IF ( R .LT. R1 ) THEN
    PK1 = PRK1(I)
ELSEIF ( R .LT. R2 ) THEN
    PK1= PRK2(I)
ELSE
    PK1 = PRK3(I)
ENDIF
RETURN
END
-----
```

INCLUDE FILES

```
CTARGET DEF
C
    INTEGER N(5), NPLAT
    REAL X(5,100), Y(5,100), LTIME
    COMMON/TARGET/ X, Y, N, NPLAT, LTIME
C
CSEED DEF
C
    INTEGER SEED(8)
    COMMON/SEED SET/ SEED
C
SMARTSS DEF
C
    REAL SIGXP, SIGYP, SIGXB, SIGYB, RATE, RSEARCH, SIGMAR, DIST
    REAL DX, DY
    INTEGER NSUB, NAPX, NAPY
    COMMON /SYSTEM/ SIGXP, SIGYP, SIGXB, SIGYB, RATE, RSEARCH, NSUB,
& SIGMAR, DIST, NAPX, NAPY, DX,DY
C
C
SEARCH DEF
C
    REAL R1, R2, PRH1(5), PRH2(5), PRH3(5), PRK1(5), PRK2(5), PRK3(3)
    COMMON /SEARCHCIRCLE/ R1, R2, PRH1, PRH2, PRH3, PRK1, PRK2, PRK3
C
```

```

      REAL FUNCTION SPLITX(ROUND, NSALVO, NAPX, DX)
C ****
C THIS FUNCTION DEVIATES THE AIMPOINT FOR LARGE TARGET
C
      INTEGER ROUND, NSALVO, NAPX, N, M
      REAL DX
      IF (NSALVO .LT. NAPX) THEN
          SPLITX = 0.
          GO TO 200
      ENDIF
      IF( INT( REAL(NAPX)/2. ) .LT. ( ( REAL(NAPX)/2.) - 0.1 ) ) THEN
          M=1
          N=0
100    CONTINUE
          IF (ROUND .LT. ((REAL(M)/REAL(NAPX) )*NSALVO + 0.7)) THEN
              SPLITX = 2.*DX/(NAPX-1)*N*((-1)**M)
              GO TO 200
          ENDIF
          M = M + 1
          N = INT( REAL(M) / 2. )
          GO TO 100
      ELSE
          M=1
          N=0
120    CONTINUE
          IF ( ROUND .LT. (( REAL(M)/REAL(NAPX) )*NSALVO + 0.6)) THEN
              SPLITX = 2.*DX/REAL(NAPX-1)*( N+.5 )*((-1)**(M+1))
              GO TO 200
          ENDIF
          M = M + 1
          N = INT( REAL(M-1) / 2. )
          GO TO 120
      ENDIF
200    CONTINUE
      RETURN
      END
C
C
      REAL FUNCTION SPLITY(ROUND, NSALVO, NAPY, DY)
C ****
C THIS FUNCTION DEVIATES THE AIMPOINT FOR DEEP TARGET
C
      INTEGER ROUND, NSALVO, NAPY, N, M
      REAL DY
      IF (NSALVO .LT. NAPY) THEN
          SPLITX = 0.
          GO TO 200
      ENDIF
      IF( INT( REAL(NAPY)/2. ) .LT. ( ( REAL(NAPY)/2.) - 0.1 ) ) THEN
          M=1
          N=0
100    CONTINUE
          IF ( ROUND .LT. (( REAL(M)/REAL(NAPY) )*NSALVO + 0.6)) THEN
              SPLITY = 2.*DY/(NAPY-1)*N*((-1)**M)
              GO TO 200
          ENDIF

```

```
M = M + 1
N = INT( REAL(M) / 2. )
GO TO 100
ELSE
M=1
N=0
120  CONTINUE
      IF ( ROUND .LT. (( REAL(M)/REAL(NAPY) )*NSALVO + 0.7)) THEN
          SPLITY = 2.*DY/REAL(NAPY-1)*( N+.5 )*(-1)**(M+1))
          GO TO 200
      ENDIF
      M = M + 1
      N = INT( REAL(M-1) / 2. )
      GO TO 120
  ENDIF
200  CONTINUE
RETURN
END
```

```

C*****
      REAL FUNCTION CONFINT (REP, STD)
C-----
      INTEGER REP
      REAL STD
      IF (REP.GT.2) THEN
          CONFINT=4.* STD/SQRT (REAL (REP-1))
      ELSE
          CONFINT = 4.
      ENDIF
      RETURN
      END
C*****
      SUBROUTINE STATISTICS (REPEAT, NEWX, AVGX, STDX)
C-----
C THIS SUBRUTINE CALCULATES THE AVERAGE OF A CURRENT
C INCREMENTED SAMPLE, AND CALLS FOR SUBRUTINE STDEV
C TO CALCULATE THE STANDARD DEVIATION.
C-----
      INTEGER REPEAT, NEWX
      REAL AVGX, STDX, XAVOLD
      XAVOLD=AVGX
C      WRITE(*,*) 'I AM IN STATISTICS REPEAT=',REPEAT
      XAVOLD=AVGX
      AVGX=(REPEAT*AVGX+NEWX)/REAL (REPEAT+1)
      CALL STDEV (REPEAT, NEWX, AVGX, STDX, XAVOLD)
      RETURN
      END
C*****
      SUBROUTINE STDEV (REPEAT, NEWX, AVGX, STDX, XAVOLD)
C-----
      INTEGER REPEAT, NEWX
      REAL AVGX, STDX ,XAVOLD, RP
      IF (REPEAT .EQ.0) THEN
          STDX=0.0
          RETURN
      ELSE
          RP=REAL (REPEAT)
          STDX=SQRT ((RP-1.)/RP*STDX**2+XAVOLD**2+NEWX**2/RP-(RP+1.)/RP
          & *AVGX**2)
      ENDIF
      RETURN
      END

```

```

C _____
C SUBROUTINE RANNUM(DISTN, SEED, RPARM1, RPARM2, IPARM, X)
C
C THIS SUBROUTINE PROVIDES AN INTERFACE WITH THE LLRANDOMII
C ROUTINES PROVIDED IN THE NONIMSL LIBRARY. THE PARAMETER
C REQUIREMENTS AND CALLING PROCEDURES ARE AS FOLLOWS:
C
C DISTN = DISTRIBUTION TYPE YOU WANT TO SELECT
C          AN INTEGER BETWEEN 1 AND 7
C SEED = THE RANDOM NUMBER SEED YOU WISH TO USE
C RPARM1, RPARM2, AND IPARM ARE REAL AND INTEGER PARAMETERS
C PASSED TO THE ROUTINE WITH MEANINGS WHICH VARY WITH THE TYPE OF
C DISTRIBUTION YOU DESIRE
C          NOTE: IPARM IS CURRENTLY NOT BEING USED.
C X = THE RETURNED RANDOM NUMBER, IT IS ALWAYS REAL
C
C DISTRIBUTION NUMBERS AND THE ASSOCIATED PARM DEFINITIONS
C
C 1--UNIFORM ON THE INTERVAL RPARM1 TO RPARM2
C 2--NORMAL WITH MEAN RPARM1 AND STD DEV RPARM2
C 3--EXPONENTIAL WITH RATE RPARM1
C 4--COUCHY WITH A = RPARM1 AND B = RPARM2
C 5--GAMMA WITH SHAPE RPARM2 AND RATE RPARM1
C 6--POISSON WITH RATE RPARM1
C 7--GEOMETRIC WITH P = RPARM1
C
C NOTE TO NEW USERS: THIS FUNCTION NOW HAS TWO CALLS TO LLRAN
C FOR EACH TYPE OF VARIATE, ONE COMPATABLE WITH THE MAINFRAME
C LLRANDOMII, AND ONE COMPATABLE WITH RNDG.LIB FOR THE PC
C THE PC VERSIONS ALL END IN 'PC'
C ONE IS ALWAYS COMMENTED OUT.
C
C VERY IMPORTANT: IF YOU ARE USING THE LLRANDOMII CALLS, MAKE
C                 SURE TO COMMENT OUT THE STATEMENT
C                 SEED = INT(PCSEED)
C
C
REAL RPARM1, RPARM2, X
INTEGER DISTN, SEED, IPARM, N
DOUBLE PRECISION PCSEED
REAL TEMP, VARIAT(1)

C
C TRANSLATION FOR PCs

C
PCSEED = DFLOAT(SEED)
N = 1

C
IF (DISTN.LE.0.OR.DISTN.GT.8) THEN
  WRITE(10, *) 'ILLEGAL CALL TO RANNUM, BAD DISTN'
  STOP
ENDIF

C
WRITE(10, *)
WRITE(10, *) '@@@@@@@@CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC'
C WRITE(*, *) 'FROM RANNUM'
C WRITE(*, *) 'DISTRIBUTION NUMBER = ', DISTN
C WRITE(*, *) 'SEED = ', SEED

```

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C      WRITE(*, *) 'PCSEED = ', PCSEED
C      WRITE(*, *) 'RPARMS ARE ', RPARM1, ' ', RPARM2
C
C      GOTO (10, 20, 30, 40, 50, 60, 70), DISTN
C
C      GENERATE A UNIFORM BETWEEN RPARM1 AND RPARM2
10    CONTINUE

      IF (RPARM1 - RPARM2.EQ.0) THEN
        WRITE(10, *) 'ILLEGAL EQUAL RPARMS IN RANNUM'
        STOP
      ENDIF
      IF (RPARM1.GT.RPARM2) THEN
        TEMP = RPARM1
        RPARM1 = RPARM2
        RPARM2 = TEMP
      ENDIF
C
C      CALL LRNDPC(PCSEED, VARIAT, N)
C      CALL LRND(SEED, VARIAT, 1, 1, 0)
C
C      VARIAT(1) = RPARM1 + (RPARM2 - RPARM1) * VARIAT(1)
C      GOTO 99
C
C      GENERATE A NORMAL WITH MEAN RPARM1 AND STDDEV RPARM2
20    CONTINUE
C      CALL LNORPC(PCSEED, VARIAT, N)
C      CALL LNORM(SEED, VARIAT, 1, 1, 0)
C      VARIAT(1) = (VARIAT(1) * RPARM2) + RPARM1
C      GOTO 99
C
C      GENERATE AN EXPONENTIAL WITH RATE (1/MEAN) RPARM1
30    CONTINUE
      IF (RPARM1.EQ.0) THEN
        WRITE(10, *) 'ILLEGAL ZERO RATE IN RANNUM'
        STOP
      ENDIF
      CALL LGAMPC(PCSEED, VARIAT, N, 1.0)
      CALL LEXPN(SEED, VARIAT, 1, 1, 0)
      VARIAT(1) = VARIAT(1) / RPARM1
      GOTO 99
C
C      GENERATE A COUCHY WITH A = RPARM1 AND B = RPARM2
40    CONTINUE
      IF (RPARM2.LE.0) THEN
        WRITE(10, *) 'ILLEGAL COUCHY SPREAD IN RANNUM, B = ', RPARM2
        STOP
      ENDIF
      CALL LCHYPC(PCSEED, VARIAT, N)
      CALL LCCHY(SEED, VARIAT, 1, 1, 0)
      VARIAT(1) = (VARIAT(1) * RPARM2) + RPARM1
      GOTO 99
C
50    CONTINUE
      IF (RPARM1.LE.0) THEN
        WRITE(10, *) 'ILLEGAL NONPOSITIVE GAMMA RATE IN RANNUM'

```

```

STOP
ENDIF
IF (RPARM2.LE.0) THEN
C      WRITE(10, *) 'ILLEGAL SHAPE PARAMETER IN RANNUML'
STOP
ENDIF
C      CALL LGAMPC(PCSEED, VARIAT, N, RPARM2)
CALL LGAMA(SEED, VARIAT, 1, 1, 0, RPARM2)
VARIAT(1) = VARIAT(1) * (1.0 / RPARM1)
GOTO 99

60   CONTINUE
IF (RPARM1.LE.0) THEN
C      WRITE(10, *) 'ILLEGAL POISSON RATE IN RANNUML'
STOP
ENDIF
C      CALL LPOIPC(PCSEED, VARIAT, N, RPARM1)
CALL LPOIS(SEED, VARIAT, 1, 1, 0, RPARM1)
GOTO 99

70   CONTINUE
IF (RPARM1.LE.0) THEN
C      WRITE(*, *) 'RETURNING ', X
C      WRITE(10, *) '@@@@@@@@CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC'
C      WRITE(10, *)
RETURN
END

```

## LIST OF REFERENCES

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